P3266071

* NOTICES *



---

CLAIMS

---

(57) [Claim(s)]
[Claim 1] A solid-state-laser crystal characterized by dope concentration distribution of said laser activity ion increasing from an end face used as an excitation side of said solid-state-laser crystal continuously or gradually toward an end face used as a cooling surface in a solid-state-laser crystal of a disk configuration which has laser activity ion.
[Claim 2] A solid-state-laser crystal according to claim 1 characterized by a continuous change of said dope concentration distribution being a straight line or a curve.
[Claim 3] A solid-state-laser crystal according to claim 1 characterized by a gradual change of said dope concentration distribution being a straight line or a curve.
[Claim 4] A solid-state-laser crystal characterized by having the inclination which increases from an excitation side in proportion to a square of distance of the thickness direction to a cooling surface toward an end face which turns into a cooling surface from an end face from which concentration of laser activity ion serves as an excitation side of said solid-state-laser crystal in a solid-state-laser crystal of a disk configuration which has laser activity ion.
[Claim 5] A solid-state-laser crystal according to claim 1 or 3 characterized by forming a gradual change of said dope concentration distribution of cementation in two or more crystals with which dope concentration of laser activity ion differs.
[Claim 6] A solid-state-laser crystal according to claim 5 characterized by two or more crystals with which said concentration differs being joined by an optical contact or diffused junction.
[Claim 7] A solid-state-laser crystal according to claim 1 characterized by joining a crystal with which laser ion activity is not doped by excitation side of said solid-state-laser crystal.
[Claim 8] Said laser activity ion is a solid-state-laser crystal according to claim 7 characterized by being Nd or Yb.
[Claim 9] a creation method of a solid state laser crystal characterize by to heat material powder of a solid state laser crystal , to be the method of pull up a crystal and create a solid state laser crystal , attach solid-state seed crystal to a material solution which material powder fused , and rotate it , to make laser activity ion concentration in said material solution increase with time amount , and to carry out the inclination of the concentration of laser activity ion along a crystal orientation .
[Claim 10] The manufacturing installation of the solid-state-laser crystal characterized by to have a means heat material powder of a solid-state-laser crystal , to be the manufacturing installation which pull up a crystal and create a solid-state-laser crystal , attach solid-state seed crystal to a material solution which material powder fused , and rotate it , to have a means to which laser activity ion in said material solution be made to increase with time amount , and to carry out the inclination of the concentration of laser activity ion along a crystal orientation .
[Claim 11] A creation method of a solid-state-laser crystal characterized by carrying out the inclination of the concentration of laser activity ion in accordance with shaft orientations of a crystal by fusing a part of perimeter of a solid-state-laser crystal with uniform concentration of laser activity ion with a heating means, and carrying out multiple-times migration of the solid-state-laser crystal perimeter from one side to another side in accordance with shaft orientations with said heating means.
[Claim 12] A heating means for fusing a part of perimeter of a solid-state-laser crystal with uniform concentration of laser activity ion, It has a means to move a relative position of said heating means and said solid-state-laser crystal to another side from one side along a crystal orientation of a solid-state-laser crystal. A manufacturing installation of a solid-state-laser crystal characterized by carrying out the inclination of the laser activity ion concentration along a crystal orientation by carrying out melting of the perimeter of a solid-state-laser crystal with said heating means, and carrying out multiple-times migration from one side to another side.
[Claim 13] a creation method of a solid state laser crystal characterize by carry out melting of some powder sintered compacts of a solid state laser crystal material with which it be join to solid-state seed crystal into which a crystal be grow up from a fused solid state laser solution , and concentration of laser activity ion have inclination in a crystal orientation partially with a heating means , and carry out the inclination of the laser activity ion concentration along a crystal orientation .
[Claim 14] A manufacturing installation of a solid-state-laser crystal characterized by creating a solid-state-laser crystal in which was equipped with the following, was made to carry out melting of said powder sintered compact partially with said heating means, and laser activity ion concentration carried out inclination in accordance with shaft orientations of a crystal. Solid-state seed crystal for growing up a crystal from a fused solid-state-laser solution A powder sintered compact of a laser crystal material with which it is combined with said solid-state seed crystal, and

concentration of laser activity ion has inclination in a crystal orientation A heating means for fusing said some of powder sintered compacts

[Claim 15] Semiconductor laser as the excitation light source A solid-state-laser crystal of a disk configuration A resonator which resonates light which carried out incidence of said semiconductor laser light, and was generated from an excitation side which is one end face of said solid-state-laser crystal It is a cooling means to a cooling surface which is an other-end side of said solid-state-laser crystal. It is solid-state-laser equipment equipped with the above, and dope concentration of laser activity ion in said solid-state-laser crystal is characterized by using a solid-state-laser crystal which has inclination which increases from an excitation side to a cooling surface.

[Claim 16] Solid-state-laser equipment according to claim 15 characterized by a concentration gradient which dope concentration of laser activity ion increases from an excitation side to a cooling surface being continuous, and having the shape of the shape of a straight line, and a curve.

[Claim 17] Solid-state-laser equipment according to claim 15 characterized by using a solid-state-laser crystal with inclination which increases from an excitation side in proportion to a square of distance of the thickness direction to a cooling surface toward an end face which turns into a cooling surface from an end face from which concentration of laser activity ion serves as an excitation side of said solid-state-laser crystal.

[Claim 18] Semiconductor laser as the excitation light source A solid-state-laser crystal of a disk configuration A resonator which resonates light which carried out incidence of said semiconductor laser light, and was generated from an excitation side which is one end face of said solid-state-laser crystal It is a cooling means to a cooling surface which is an other-end side of said solid-state-laser crystal. It is solid-state-laser equipment equipped with the above, and is characterized by contacting said cooling means to the crystal face where said dope concentration is high using a solid-state-laser crystal joined so that it might become the inclination with which said dope concentration increases two or more crystals with which dope concentration of laser activity ion differs to a cooling surface from an excitation side.

[Claim 19] Solid-state-laser equipment according to claim 18 characterized by two or more crystals with which said concentration differs being joined by an optical contact or diffused junction.

[Claim 20] Solid-state-laser equipment according to claim 15 characterized by joining a crystal with which laser ion activity is not doped by excitation side of a solid-state-laser crystal.

---

[Translation done.]

---

DETAILED DESCRIPTION

---

[Detailed Description of the Invention]
[0001]
[The technical field to which invention belongs] This invention relates to the creation method of a solid-state-laser crystal, the solid-state-laser equipment using this, and a solid-state-laser crystal, and its manufacturing installation about the solid-state-laser equipment which makes semiconductor laser the source of excitation.
[0002]
[Description of the Prior Art] By the technical progress of high power semiconductor laser in recent years, development of the semiconductor laser excitation solid state laser which changes to the conventional discharge lamp excitation is activating. Semiconductor laser excitation has a well head, high beam quality, and which small and long lasting feature compared with discharge lamp excitation. Fundamentally, the increment in the semiconductor laser luminous intensity to input can attain the high increase in power of semiconductor laser excitation solid state laser. However, the problem that beam quality deteriorates produces a high increase in power and high beam quality by the increment in the refractive-index distribution accompanying the temperature rise in a crystal, and a heat strain as they have the relation of a trade-off and make the semiconductor laser light to input increase.
[0003] The active mirror method which carries out end-face excitation of the thin disk mold laser crystal as one policy which solves this, and carries out end-face cooling from a rear face is proposed. The semiconductor laser excitation solid state laser of an active mirror method is described at details from laser research, the 24th volume, and 59 pages, for example to "65 pages."
[0004] Drawing 24 is drawing showing an example of conventional solid-state-laser equipment. The solid-state-laser crystals 11 are the diameter of 6mm, and a disk configuration with a thickness of 2mm, and the homogeneity dope of Nd3+ which is laser activity ion by 1.4atm% concentration is carried out mostly at the base material of an yttrium aluminum garnet (YAG). To the wavelength of the excitation light 19 and the solid-state-laser light 20, nonreflective coating is performed to the excitation side 17 of the solid-state-laser crystal 11, and high reflective coating is given to the cooling surface 18. When the excitation light 19 with a wavelength of 880nm outputted from semiconductor laser 16 goes and comes back to under the solid-state-laser crystal 11 with a thickness of 2mm one time, 90% of energy is absorbed during a solid-state-laser crystal.
[0005] Next, about how to create the conventional solid-state-laser crystal, the case of a neodium:YAG (Nd:YAG) crystal is mentioned as an example, and is explained.
[0006] Drawing 25 is drawing for explaining the creation method of the conventional solid-state-laser crystal, and has shown the training furnace of the crystal by the Czochralski method. aluminum 2O3 which serves as a raw material of Nd:YAG into the crucible 29 made from Ir first in the Czochralski method, and Y2 O3 And Nd 2O3 The powder of a high grade is put in, and it pulls up, attaching the YAG seed crystal 26 which melted powder, was made to generate the Nd:YAG solution 31, and was held at the tip of the alumina rod 32 in the Nd:YAG solution 31, and rotating it slowly with the coil 31 for induction heating.
[0007] The segregation coefficient of a material proper exists in the crystal of laser activity ion and a base material. When a segregation coefficient is 1, the concentration distribution which met the shaft orientations of a crystal is not produced, but the segregation coefficient to YAG of Nd is one or less, and activity ion concentration has the distribution which becomes thin as it is pulled up. For this reason, by the conventional training method, rotational speed and raising speed were set as about per hour 1mm per minute 20 times, respectively, and the solid-state-laser crystal which has uniform concentration in accordance with shaft orientations was raised so that concentration might become homogeneity to the shaft orientations of a crystal as much as possible. Then, it cut in desired magnitude, areflaxia and high reflective coating were given after polishing, and the solid-state-laser crystal was created.
[0008] Next, actuation of conventional solid-state-laser equipment is explained with reference to drawing 24 .
[0009] The excitation light 19 outputted from semiconductor laser 16 lets the condensing optical system 13 pass, and inputs it into a solid-state-laser crystal. 90% or more of energy is mostly absorbed by the solid-state-laser crystal 11 by turning up the excitation light 19 in the cooling surface 18 of the solid-state-laser crystal 11. A part of light absorbed by the solid-state-laser crystal 11 is changed into heat, and it is outputted from the output mirror 14 as a solid-state-laser light 20 whose part is the wavelength of 1064nm.
[0010] By the above-mentioned active mirror method, ideally, since the temperature distribution in a crystal are distributed in the thickness direction at a single dimension, the optical axis and temperature gradient vector of laser oscillation become parallel, and a thermal lensing effect is controlled. Furthermore, since the distance of an exoergic

location and a cooling surface can take short, efficient cooling is attained.
[0011]
[Problem(s) to be Solved by the Invention] Since the magnitude of a trouble of a laser crystal and excitation light is limited and a temperature gradient arises in the shape of an ellipse with a peak of the condensing section of the excitation light on the surface of a crystal, the depressor effect of the heat lens mentioned above will decrease. Furthermore, as the conventional laser crystal, since the laser activity ion concentration doped by the base material is fixed, the great portion of excitation light will be absorbed on the laser crystal surface, and there is a defect that the temperature of the laser crystal surface tends to rise.
[0012] Drawing 26 is drawing having shown the amount 22 of excitation absorption of light of a under [ the crystal of the solid-state-laser crystal set up so that thickness of a crystal might be made to 4mm, it might make activity ion concentration 1.4atm(s)% and 99% of excitation light might be absorbed during a crystal ]. In addition, the absorbed amount expresses the crystal with the rate when dividing into 16 in the thickness (4mm) direction. A great portion of excitation light will be absorbed in respect of excitation of a crystal so that more clearly than drawing 26 . Consequently, the temperature rise in a crystal becomes the highest in respect of [ 17 (location of a horizontal axis 0) ] excitation of the solid-state-laser crystal 11.
[0013] Drawing 27 has shown the count result of the rise temperature 23 when inputting the excitation light of 10W into the solid-state-laser crystal of the above-mentioned active mirror method. Distance from the crystal center 23 where d and excitation light are irradiated in the distance from the excitation side 17 to a cooling surface 18 to the crystal side was set to r among drawing 27 , and the temperature change was set to T. In addition, in count, it is assumed that the energy of the abbreviation 1/3 of the absorbed excitation light 19 is changed into heat. Furthermore, in count, since the cooling effect from the excitation side 17 and the side 25 of the solid-state-laser crystal 11 is not taken into consideration, an actual temperature rise becomes lower than count. It turns out that temperature rises most in respect of solid-state-laser excitation so that more clearly than drawing 27 . In order that the cooling effect may decrease, this becomes a big demerit, so that it separates from a cooling surface. Although it is dependent on the parameter of a thermal configuration change of a crystal or a resonator in addition to temperature distribution about the quality of a beam, in this condition, it becomes difficult to perform a high increase in power further, maintaining the high quality of a beam.
[0014] The purpose of this invention controls the heat strain accompanying a high increase in power, and is to offer the creation method of the solid-state-laser crystal used for the solid-state-laser equipment and this which can take out a quality beam.
[0015]
[Means for Solving the Problem] A solid-state-laser crystal of this invention is characterized by dope concentration distribution of said laser activity ion changing to a crystal orientation of said solid-state-laser crystal in a solid-state-laser crystal of a disk configuration which has laser activity ion.
[0016] Moreover, a solid-state-laser crystal of this invention is characterized by dope concentration distribution of said laser activity ion increasing from an end face used as an excitation side of said solid-state-laser crystal continuously or gradually toward an end face used as a cooling surface in a solid-state-laser crystal of a disk configuration which has laser activity ion.
[0017] Moreover, gradual change of dope concentration distribution is characterized by being formed of cementation and two or more crystals with which dope concentration of laser activity ion differs being. Moreover, it is characterized by joining a crystal with which laser ion activity is not doped by excitation side of a solid-state-laser crystal. Moreover, it is characterized by two or more crystals with which concentration differs being joined by an optical contact or diffused junction. Moreover, it is characterized by laser activity ion being Nd or Yb.
[0018] The creation method of the solid-state-laser crystal of this invention by churning of a material solution is the creation method of a solid-state-laser crystal of pulling up a crystal, and a material solution agitates with a churning means with rotation raising, the activation segregation coefficient in the material solution of a solid-state-laser crystal brings close to the segregation coefficient of a proper, and it carries out carrying out the inclination of the laser activity ion concentration along a crystal orientation as the feature, attaching solid-state seed crystal to the material solution which heated material powder of a solid-state-laser crystal, and material powder fused,
[0019] It carries out that the manufacturing installation of the solid-state-laser crystal of this invention by churning of a material solution is the solid-state-laser crystal manufacturing installation which pulls up a crystal, attaching solid-state seed crystal to the material solution which has a means heat material powder of a solid-state-laser crystal, and material powder fused, and rotating it, is equipped with a means agitate a material solution, brings the activation segregation coefficient in the material solution of a solid-state-laser crystal close to the segregation coefficient of a proper by churning, and carries out the inclination of the laser activity ion concentration along a crystal orientation as
[0020] the creation method of the solid state laser crystal using the crucible of different ion concentration be the creation method of a solid state laser crystal of pull up a crystal , attach solid-state seed crystal to the material solution which heated the material powder of a solid state laser crystal , and a material powder fused , and rotate it , attach seed crystal in order of a material solution with high laser activation ion concentration , and be characterize by to carry out the inclination of the laser activity ion concentration along a crystal orientation to two or more material solutions with which the concentration of laser activity ion differ .
[0021] The manufacturing installation of the solid-state-laser crystal using the crucible of different ion concentration is the manufacturing installation of a solid-state-laser crystal which pulls up a crystal, attaching

solid-state seed crystal to the material solution which has a means heat material powder of a solid-state-laser crystal, and material powder fused, and rotating it, and is characterized by to have two or more material solutions with which the concentration of laser activity ion differs, and to have a means attach seed crystal in order of a material solution with high laser active substance concentration.

[0022] The creation method of the solid-state-laser crystal of a material solution which carries out the increment in ion concentration is the method of pulling up a crystal and creating a solid-state-laser crystal, makes the laser activity ion concentration in said material solution increase with time amount, and is characterized by to carry out the inclination of the laser activity ion concentration in accordance with shaft orientations, attaching solid-state seed crystal to a material solution which heated material powder of a solid-state-laser crystal, and material powder fused, and rotating it.

[0023] The manufacturing installation of the solid-state-laser crystal of a material solution which carries out the increment in ion concentration is the manufacturing installation which pulls up a crystal and creates a solid-state-laser crystal, has the means to which the laser activity ion in said material solution makes increase with time amount, and is characterize by to carry out the inclination of the laser activity ion concentration in accordance with shaft orientations, attach solid-state seed crystal to the material solution which has a means heat material powder of a solid-state-laser crystal, and material powder fused, and rotate it.

[0024] A creation method of a solid-state-laser crystal characterized by carrying out the inclination of the laser activity ion concentration in accordance with shaft orientations of a crystal by fusing a part of perimeter of a solid-state-laser crystal with uniform laser activity ion concentration with a heating means, and carrying out multiple-times migration from one side to another side in accordance with shaft orientations of a solid-state-laser crystal with said heating means.

[0025] The manufacturing installation of the solid-state-laser crystal characterized by to carry out the inclination of the laser activity ion concentration in accordance with the shaft orientations of a crystal by having a heating means for fusing a part of perimeter of a solid-state-laser crystal with uniform laser activity ion concentration, and a means move a relative position of said heating means and solid-state-laser crystal to another side from one side along a crystal orientation of a solid-state-laser crystal, and carrying out melting of said heating means, and carrying out the multiple-times migration of the perimeter of a solid-state-laser crystal from one side to another side.

[0026] A creation method of a solid-state-laser crystal by heating of a sintered compact is characterized by carrying out melting of some powder sintered compacts of a solid-state-laser crystal material with which it is joined to solid-state seed crystal into which a crystal is grown up from a fused solid-state-laser solution, and laser activity ion concentration has inclination in shaft orientations partially with a heating means, and laser activity ion concentration carrying out inclination in accordance with shaft orientations of a crystal.

[0027] A manufacturing installation of a solid-state-laser crystal by heating of a sintered compact A powder sintered compact of a laser crystal material with which solid-state seed crystal for growing up a crystal from a fused solid-state-laser solution is combined, and laser activity ion concentration has inclination in shaft orientations, It is characterized by heating means for fusing said some of powder sintered compacts, and creating a solid-state-laser crystal in which was made to carry out melting of said powder sintered compact partially with said heating means, and laser activity ion concentration carried out inclination in accordance with shaft orientations of a crystal.

[0028] Solid-state-laser equipment of this invention Semiconductor laser as the excitation light source, and a solid-state-laser crystal of a disk configuration, In solid-state-laser equipment which equipped with a cooling means a resonator which resonates light which carried out incidence of said semiconductor laser light, and was generated from an excitation side which is one end face of said solid-state-laser crystal, and a cooling surface which is an other-end side of said solid-state-laser crystal Dope concentration of laser activity ion in said solid-state-laser crystal is characterized by using a solid-state-laser crystal which has inclination which increases from an excitation side to a cooling surface. Moreover, it is characterized by using a solid-state-laser crystal with inclination which increases from an excitation side in proportion to a square of distance of the thickness direction to a cooling surface toward an end face which turns into a cooling surface from an end face from which concentration of laser activity ion serves as an excitation side of said solid-state-laser crystal.

[0029] Solid-state-laser equipment of this invention Semiconductor laser as the excitation light source, and a solid-state-laser crystal of a disk configuration, In solid-state-laser equipment which equipped with a cooling means a resonator which resonates light which carried out incidence of said semiconductor laser light, and was generated from an excitation side which is one end face of said solid-state-laser crystal, and a cooling surface which is an other-end side of said solid-state-laser crystal It is characterized by contacting said cooling means to the crystal face where said dope concentration is high using a solid-state-laser crystal joined so that it might become the inclination with which said dope concentration increases two or more crystals with which dope concentration of laser activity ion differs to a cooling surface from an excitation side.

[0030] It is characterized by two or more crystals with which concentration differs being joined by an optical contact or diffused junction.

[0031] It is characterized by joining a crystal with which laser ion activity is not doped by excitation side of a solid-state-laser crystal.

[0032]

[Embodiment of the Invention] The solid-state-laser crystal and the creation method of this invention, a manufacturing installation, and the solid-state-laser equipment using a solid-state-laser crystal are explained to

details with reference to a drawing.
[0033] **** of the solid-state-laser equipment used by introduction this invention — with reference to ******, it explains just. Drawing 1 is drawing showing the whole solid-state-laser equipment configuration used in the example of this invention. Solid-state-laser equipment has the output mirror 14 for taking out the condensing optical system 13 for condensing the semiconductor laser 16 for exciting the solid-state-laser crystal 11, and the excitation light 19 into the solid-state-laser crystal 11 and the excitation light reflex mirror 15, the heat sink 12 that cools the solid-state-laser crystal 11, and the solid-state-laser light 20. The nonreflective coat and the high reflective coat are given to the excitation side 17 and cooling surface 18 of the solid-state-laser crystal 11 to the wavelength of the excitation light 19 and the solid-state-laser light 14, respectively.
[0034] Next, actuation of the solid-state-laser equipment of drawing 1 is explained. The excitation light 19 outputted from semiconductor laser 16 is irradiated during the solid-state-laser crystal 11 from the condensing optical system 13. The excitation light 19 is turned up with the high reflective film of the cooling surface 18 of the solid-state-laser crystal 11, and carries out incidence to the excitation light reflex mirror 15. When turned up by the excitation light reflex mirror 15, incidence of the excitation light 19 is again carried out to the solid-state-laser crystal 11. Thereby, 99% of energy of the excitation light 19 is absorbed by the solid-state-laser crystal 11. A part is changed into heat and, as for the light absorbed by the solid-state-laser crystal 11, a part is outputted as a solid-state-laser light 20 which is the wavelength of 1064nm.
[0035] Next, the 1st example of the solid-state-laser crystal of this invention is explained. The 1st example of a solid-state-laser crystal is 4mm in the diameter of 6mm, and thickness, and the concentration of laser activity ion is the crystal of Nd:YAG which increased in the thickness direction in proportion to distance like drawing 2 . In this example, the laser activity ion concentration in the excitation side 17 and a cooling surface 18 is 0.1 and 1.3atm%, respectively. The wavelength of the semiconductor laser light by this crystal is 880nm and output 10W, and is absorbed during a crystal of 99% of energy by going and coming back to under the crystal of this example two times.

[0036] Next, the effect when using the 1st example of the solid-state-laser crystal of this invention is explained. Drawing 3 plots the rate of the excitation light 19 absorbed during the solid-state-laser crystal 11 in the example of this invention from the excitation side 17 to shaft orientations between cooling surfaces 18. In addition, the rate when dividing the solid-state-laser crystal 11 into 16 in the thickness direction has shown the amount 22 of excitation light absorption. As the crystal of the 1st example, by the cooling surface 18 side, since the concentration of laser activity ion is high, the excitation absorption of light is large at a cooling surface 18 side, and since pyrexia becomes large, efficient cooling in a cooling surface is attained.
[0037] Drawing 4 is the result of calculating the temperature distribution in the crystal of the 1st example of a solid-state-laser crystal. Since the amount of excitation absorption of light becomes large near the cooling surface, while the peak of a temperature rise moves to a cooling surface side, it turns out that a rise value is held down by 26 or less degrees. In addition, also in this count, since the cooling effect from the excitation side 17 and the side 25 of the solid-state-laser crystal 11 is not taken into consideration, a temperature rise will be controlled further in fact.
[0038] Next, the 2nd example of the solid-state-laser crystal of this invention is explained. If it is made to increase more than the concentration in the second half of a 1atm% base in Nd:YAG shown in the 1st example of a solid-state-laser crystal, since the fall of a top level life will be produced, there is a limit in making concentration of activity ion high more than this. Therefore, the thickness of about 4mm is needed as thickness. On the other hand, ITTORIBIUMU which is the 2nd example of a solid-state-laser crystal: In YAG (Yb:YAG), the dope of activity ion is possible, without producing the fall of a top level life to 20atm%.
[0039] Drawing 5 expresses concentration 21 distribution of the laser activity ion under crystal at the time of changing to a Nd:YAG crystal and using a Yb:YAG crystal. In Yb:YAG, since a high concentration dope is attained compared with Nd:YAG, 99% of energy of excitation light will be absorbed by going and coming back to under a crystal with a thickness of 1.5mm two times.
[0040] Drawing 6 expresses the rise temperature distribution at the time of using the above-mentioned solid-state-laser crystal. Since thickness can be made thin in Yb:YAG, much more cooling effect from a cooling surface will be acquired, and the peak of rise temperature will be controlled by about 24.7 degrees.
[0041] In addition, although the solid-state-laser equipment of this invention described the arrangement which arranges the semiconductor laser 16 which is the excitation light 19 in a V character mold, and takes out the solid-state-laser light 20 perpendicularly to the solid-state-laser crystal 11, it can acquire the depressor effect of a temperature rise for the same configuration as the conventional example very much.
[0042] Next, the creation method of the solid-state-laser crystal of this invention and the manufacturing installation of a solid-state-laser crystal are stated to details using a drawing.
[0043] Drawing 7 is the block diagram of the 1st example which is the manufacturing installation of the solid-state-laser crystal of this invention, and differing from the manufacturing installation of the conventional solid-state-laser crystal is the point of having HANE 33 for churning for agitating the Nd:YAG solution 31 compulsorily. HANE 33 for churning is held at the rotating alumina rod 32, and agitates a Nd:YAG solution compulsorily by rotating with the alumina rod 32. By the conventional creation method, rotational speed and raising speed were slowly pulled up to about per hour 1mm per minute 20 times, respectively, and the solid-state-laser crystal which has uniform concentration in accordance with shaft orientations was raised so that concentration might become homogeneity to the shaft orientations of a crystal as much as possible. In this example, it is agitating the solution of Nd:YAG for

rotational speed and raising speed compulsorily with a churning means like the creation method of the conventional solid-state-laser crystal, and the effective segregation coefficient to YAG of Nd is brought close to the segregation coefficient of a proper, and it becomes raisable [ the laser crystal which has a steep concentration gradient compared with the conventional training method ].
[0044] In this example, although how to rotate HANE for churning which is a compulsory churning means with the alumina rod 32 was explained, it is also possible to establish a driving means independently and to perform compulsory churning. Moreover, in this example, training of the laser crystal which has a steep concentration gradient, without using a churning means by being referred to as about per hour 1.5-2.5mm is also possible by making rotational speed and raising speed quicker than the creation method of the conventional solid-state-laser crystal.
[0045] Drawing 8 expresses distribution of the activity ion concentration 34 under solid-state-laser crystal when creating using the manufacturing installation of the solid-state-laser crystal by this invention. The length of a crystal is expressed with the relative value and the relative length 1 is equivalent to seed crystal side 38. Concentration is expressed with the relative value to the laser activity ion concentration in the Nd:YAG solution 31. A concentration gradient becomes steep as it goes to seed crystal side 38, so that more clearly than drawing 8 . Creation of a solid-state-laser crystal with a free concentration gradient is attained by changing the laser activity ion concentration in the Nd:YAG solution 31 so that clearly also from expressing the concentration of a crystal with relative concentration. moreover, the inclination a35 out of the created Nd:YAG crystal 27, inclination b36, and inclination c37 — creation of a solid-state-laser crystal with a free concentration gradient is attained by starting each portion.
[0046] Next, the creation method of the solid-state-laser crystal of this invention and the 2nd example of a manufacturing installation are described.
[0047] Drawing 9 is the block diagram of the 2nd example of the manufacturing installation of a solid-state-laser crystal, and has the crystal migration device 39 for moving in order the crucible 29 made from Ir and solid-state-laser crystal containing four kinds of solutions a40 with which laser activity ion concentration differs, a solution b41, a solution c42, and a solution d43 to a solution a40 - a solution d43. Laser activity ion concentration is set up so that it may become low, as it is the highest with a solution a40 and goes to a solution d43.
[0048] By the creation method of the solid-state-laser crystal of this example, a crystal is first grown up in a solution a40. When the desired length is reached, the Nd:YAG crystal 27 is moved to a solution b41 according to the crystal migration device 39, and a crystal is grown up again. Even a solution d43 repeats this. Thereby, creation of the crystal which has inclination in the length direction of a crystal is attained.
[0049] Drawing 10 expresses distribution of the laser activity ion concentration 48 under solid-state-laser crystal by the creation method of the solid-state-laser crystal of this example. Inclination a44, inclination b45, inclination c46, and inclination d47 are concentration gradients created in the solution a40, the solution b41, the solution c42, and the solution d43, respectively. Although it is difficult completely linear to make inclination, the depressor effect of temperature rise sufficient also as a solid-state-laser crystal with inclination like drawing 10 can be acquired. Moreover, by increasing the class of solution with which concentration differs, creation of a crystal with a more uniform concentration gradient is attained, and it is **.
[0050] In this example, although how to move a solid-state-laser crystal was explained, even if it moves a solution, creation of a crystal is possible.
[0051] Next, the creation method of the solid-state-laser crystal of this invention and the 3rd example of a manufacturing installation are described.
[0052] drawing 11 — the block diagram of the manufacturing installation of a solid-state-laser crystal — it is — the inside of the Nd:YAG solution 31 — a laser active substance — a raw material — Nd 2O3 The laser active substance inlet 49 for pouring in powder is formed.
[0053] Nd 2O3 which is the raw material powder of a laser active substance in the crucible 29 made from Ir first in the creation method of the solid-state-laser crystal by this example aluminum 2O3 to remove and Y2O3 Only powder is introduced and the YAG crystal with which a laser active substance is not contained is grown up. Then, it is Nd 2O3 from the laser active substance inlet 49 in time amount. Powder is poured in. By being able to make the laser activity ion concentration in the Nd:YAG solution 31 increase with time amount, and changing the injection rate and impregnation time amount of a laser active substance by this method, concentration is low at a seed crystal side, and it becomes possible to grow up a crystal with the concentration gradient which becomes so high that it separates.
[0054] Next, the creation method of the solid-state-laser crystal of this invention and the 4th example of a manufacturing installation are described.
[0055] In the manufacturing installation of the laser crystal in drawing 12 , the solid-state-laser crystal 50 with uniform concentration is held between the movable heaters 50 in accordance with the shaft orientations of a crystal, and a heater 50 moves to the right from the left, heating some crystals and making the zone of melting. By repeating such an activity, Nd3+ which is laser activity ion will move to right-hand side gradually.
[0056] Drawing 13 expresses distribution of the laser activity ion concentration under solid-state-laser crystal when using the creation method of the above-mentioned laser crystal. Concentration is expressed with the relative value to the concentration of the laser activity ion of the early Nd:YAG crystal 51, and early concentration is equivalent to a curve a52. Migration of a heater 50 is changed and concentration distribution of laser activity ion changes with ****** from a curve b53 to a curve d55. By this creation method, the creation method of a crystal with a still

steeper concentration gradient becomes possible by the difference in the concentration of the crystal used in early stages, and the count of migration of a heater 50.
[0057] Next, the creation method of the solid-state-laser crystal of this invention and the 5th example of a manufacturing installation are described.
[0058] When drawing 14 is referred to, the manufacturing installation of the solid-state-laser crystal of this invention is the YAG seed crystal 26 held at the alumina rod 56 and aluminum 2O3 used as the raw material of Nd:YAG, Y2 O3, and Nd 2O3. It has the infrared generator 59 for generating the infrared radiation 60 for carrying out heating melting of some of Nd:YAG sintered compacts 58 which made the powder of a high grade sinter, and Nd:YAG sintered compacts 58. Beforehand, in the concentration of Nd 2O3 used as the raw material of laser activity ion, the Nd:YAG sintered compact 58 is created so that it may have inclination in shaft orientations. The infrared generator 59 has the migration device 61 for moving up and down while revolving around the Nd:YAG sintered compact 59.
[0059] Setting to this creation method, heating and carrying out melting of some Nd:YAG sintered compacts 58, from the YAG seed crystal 26 on a drawing, it rotates to down and the infrared generator 59 moves to it. Thereby, from the YAG seed crystal 26 side, whether it is the crystal of the Nd:YAG sintered compact 58 starts gradually, and a solid-state-laser crystal with the concentration gradient of the laser activity ion according to the concentration gradient of the laser activity ion in the Nd:YAG sintered compact 58 is created. In this creation method, creation of a solid-state-laser crystal with a free concentration gradient is attained by changing the concentration of the laser activity ion contained in the Nd:YAG sintered compact 58.
[0060] Next, the 2nd example of the solid-state-laser crystal of this invention is explained to details with reference to a drawing.
[0061] The concentration 62 of laser activity ion is made to increase from an excitation side in proportion to the square of the distance of the thickness direction to a cooling surface like drawing 15 in this example to a Nd:YAG solid-state-laser crystal with a diameter [ of 6mm ], and a thickness of 4mm. The activity ion concentration in the excitation side 17 and a cooling surface 18 is 0.2 and 1.4atm%, respectively. By having such concentration distribution shows that the amount 63 of excitation light absorption absorbed during a solid-state-laser crystal becomes large by the cooling surface side further compared with the crystal which has a linear concentration gradient as shown in drawing 16 .
[0062] Drawing 17 expresses the count result of the rise temperature when exciting a solid-state-laser crystal by the semiconductor laser of 10W. While the peak of rise temperature moves to a cooling surface side compared with the example of drawing 2 of a solid-state-laser crystal, peak value becomes possible [ controlling further ] compared with the case where it has the linear concentration gradient of 23.4 degrees and drawing 2 .
[0063] Next, the 3rd example of the laser crystal of this invention is explained to details with reference to a drawing.

[0064] Drawing 18 (a) expresses the side elevation of the solid-state-laser crystal of this invention, and drawing 18 (b) expresses concentration distribution of laser activity ion. As for the solid-state-laser crystal of this invention, reference of drawing 18 joins the crystal of four different sheets of laser activity ion concentration. It is joined to order with low concentration from the crystal a65 with the lowest concentration, and a crystal a65 is arranged in the excitation side 17, and the crystal d68 is arranged in the cooling surface 18.
[0065] Drawing 19 expresses the amount 69 of excitation absorption of light, and an absorbed amount becomes large as it goes to a crystal d68 from a crystal a65. Furthermore, if the number of partitions of a crystal is increased, the example of drawing 2 will be approached.
[0066] Drawing 20 expresses the count result of the rise temperature when exciting a solid-state-laser crystal by the semiconductor laser of 10W. The peak value of rise temperature is 28.3 degrees, and the depressor effect of a temperature rise as well as the example of drawing 2 is acquired.
[0067] Next, how to create the 3rd example of a solid-state-laser crystal is described.
[0068] 1mm in the diameter of 6mm, and thickness, and laser activity ion concentration — respectively — 0.35 and 0. — it is 7, 1.05, and 1.4atm% and what ground the both ends of the crystal which is four sheets whose crystallographics axis corresponded at lambda/10, and parallelism 1 second is joined by the optical contact. It enables this to create the solid-state-laser crystal which the optical loss in a plane of composition hardly produces.

[0069] In this example, although only the creation method of the crystal by the optical contact was described, creation by diffused junction is also possible.
[0070] Next, the 4th example of the solid-state-laser crystal of this invention is explained to details with reference to a drawing.
[0071] Drawing 21 (a) expresses the side elevation of the solid-state-laser crystal of this invention, and drawing 21 (b) expresses concentration distribution of laser activity ion. As for the solid-state-laser crystal of this invention, reference of drawing 21 joins the crystal of two sheets of the crystal b with inclination with linear crystal a70 and concentration gradient by which laser activity ion is not doped. The plane of composition of Crystal b is a field where concentration is low, and another field is arranged in the cooling surface.
[0072] Drawing 22 expresses the rate 73 of the amount of excitation absorption of light, in a crystal a70, the excitation absorption of light does not happen but excitation light is absorbed as a crystal b74.
[0073] Drawing 23 expresses the count result of the rise temperature when exciting a solid-state-laser crystal by the semiconductor laser of 10W. The peak value of rise temperature is 25.8 and the temperature depressor effect of 0.2 is acquired compared with the example shown in drawing 2 . In fact, since the cooling effect from the side is

acquired, in this example it is twice whose surface area of the side of this compared with the example of drawing 2, the depressor effect of temperature is acquired more. Furthermore, as a crystal a70, since the excitation absorption of light does not happen, the increase of the thickness of a crystal, and in order that [ even if it carries out, ] the depressor effect of a temperature rise may not decrease, the strong rise effect over a mechanical strain is acquired. Moreover, in the 4th example, although dope concentration serves as a straight line, it is not restricted to this, and it can use also for the solid-state-laser crystal stated in the 1st of a solid-state-laser crystal - the 3rd example.
[0074] In addition, Nd or Yb can be used for the 2nd of a solid-state-laser crystal - the 4th example as laser activity ion.
[0075]
[Effect of the Invention] In this invention, since the solid-state-laser crystal in a cooling surface with activity ion concentration higher than an excitation side is used, efficient cooling is attained. For this reason, the temperature rise in the solid-state-laser crystal at the time of a high increase in power can be controlled, and it becomes possible to control deterioration of the beam quality accompanying a high increase in power.

---

[Translation done.]

## TECHNICAL FIELD

[A technical field to which invention belongs] This invention relates to a creation method of a solid-state-laser crystal, solid-state-laser equipment using this, and a solid-state-laser crystal, and its manufacturing installation about solid-state-laser equipment which makes semiconductor laser a source of excitation.

[Translation done.]

PRIOR ART

[Description of the Prior Art] By the technical progress of high power semiconductor laser in recent years, development of the semiconductor laser excitation solid state laser which changes to the conventional discharge lamp excitation is activating. Semiconductor laser excitation has a well head, high beam quality, and which small and long lasting feature compared with discharge lamp excitation. Fundamentally, the increment in the semiconductor laser luminous intensity to input can attain the high increase in power of semiconductor laser excitation solid state laser. However, the problem that beam quality deteriorates produces a high increase in power and high beam quality by the increment in the refractive-index distribution accompanying the temperature rise in a crystal, and a heat strain as they have the relation of a trade-off and make the semiconductor laser light to input increase.
[0003] The active mirror method which carries out end-face excitation of the thin disk mold laser crystal as one policy which solves this, and carries out end-face cooling from a rear face is proposed. The semiconductor laser excitation solid state laser of an active mirror method is described at details from laser research, the 24th volume, and 59 pages, for example to "65 pages."
[0004] Drawing 24 is drawing showing an example of conventional solid-state-laser equipment. The solid-state-laser crystals 11 are the diameter of 6mm, and a disk configuration with a thickness of 2mm, and the homogeneity dope of Nd3+ which is laser activity ion by 1.4atm% concentration is carried out mostly at the base material of an yttrium aluminum garnet (YAG). To the wavelength of the excitation light 19 and the solid-state-laser light 20, nonreflective coating is performed to the excitation side 17 of the solid-state-laser crystal 11, and high reflective coating is given to the cooling surface 18. When the excitation light 19 with a wavelength of 880nm outputted from semiconductor laser 16 goes and comes back to under the solid-state-laser crystal 11 with a thickness of 2mm one time, 90% of energy is absorbed during a solid-state-laser crystal.
[0005] Next, about how to create the conventional solid-state-laser crystal, the case of a neodium:YAG (Nd:YAG) crystal is mentioned as an example, and is explained.
[0006] Drawing 25 is drawing for explaining the creation method of the conventional solid-state-laser crystal, and has shown the training furnace of the crystal by the Czochralski method. aluminum 2O3 which serves as a raw material of Nd:YAG into the crucible 29 made from Ir first in the Czochralski method, and Y2 O3 And Nd 2O3 The powder of a high grade is put in, and it pulls up, attaching the YAG seed crystal 26 which melted powder, was made to generate the Nd:YAG solution 31, and was held at the tip of the alumina rod 32 in the Nd:YAG solution 31, and rotating it slowly with the coil 31 for induction heating.
[0007] The segregation coefficient of a material proper exists in the crystal of laser activity ion and a base material. When a segregation coefficient is 1, the concentration distribution which met the shaft orientations of a crystal is not produced, but the segregation coefficient to YAG of Nd is one or less, and activity ion concentration has the distribution which becomes thin as it is pulled up. For this reason, by the conventional training method, rotational speed and raising speed were set as about per hour 1mm per minute 20 times, respectively, and the solid-state-laser crystal which has uniform concentration in accordance with shaft orientations was raised so that concentration might become homogeneity to the shaft orientations of a crystal as much as possible. Then, it cut in desired magnitude, areflaxia and high reflective coating were given after polishing, and the solid-state-laser crystal was created.
[0008] Next, actuation of conventional solid-state-laser equipment is explained with reference to drawing 24 .
[0009] The excitation light 19 outputted from semiconductor laser 16 lets the condensing optical system 13 pass, and inputs it into a solid-state-laser crystal. 90% or more of energy is mostly absorbed by the solid-state-laser crystal 11 by turning up the excitation light 19 in the cooling surface 18 of the solid-state-laser crystal 11. A part of light absorbed by the solid-state-laser crystal 11 is changed into heat, and it is outputted from the output mirror 14 as a solid-state-laser light 20 whose part is the wavelength of 1064nm.
[0010] By the above-mentioned active mirror method, ideally, since the temperature distribution in a crystal are distributed in the thickness direction at a single dimension, the optical axis and temperature gradient vector of laser oscillation become parallel, and a thermal lensing effect is controlled. Furthermore, since the distance of an exoergic location and a cooling surface can take short, efficient cooling is attained.

[Translation done.]

---

## EFFECT OF THE INVENTION

---

[Effect of the Invention] In this invention, since the solid-state-laser crystal in a cooling surface with activity ion concentration higher than an excitation side is used, efficient cooling is attained. For this reason, the temperature rise in the solid-state-laser crystal at the time of a high increase in power can be controlled, and it becomes possible to control deterioration of the beam quality accompanying a high increase in power.

---

[Translation done.]

---

TECHNICAL PROBLEM

---

[Problem(s) to be Solved by the Invention] Since the magnitude of a trouble of a laser crystal and excitation light is limited and a temperature gradient arises in the shape of an ellipse with a peak of the condensing section of the excitation light on the surface of a crystal, the depressor effect of the heat lens mentioned above will decrease. Furthermore, as the conventional laser crystal, since the laser activity ion concentration doped by the base material is fixed, the great portion of excitation light will be absorbed on the laser crystal surface, and there is a defect that the temperature of the laser crystal surface tends to rise.
[0012] Drawing 26 is drawing having shown the amount 22 of excitation absorption of light of a under [ the crystal of the solid-state-laser crystal set up so that thickness of a crystal might be made to 4mm, it might make activity ion concentration 1.4atm(s)% and 99% of excitation light might be absorbed during a crystal ]. In addition, the absorbed amount expresses the crystal with the rate when dividing into 16 in the thickness (4mm) direction. A great portion of excitation light will be absorbed in respect of excitation of a crystal so that more clearly than drawing 26 . Consequently, the temperature rise in a crystal becomes the highest in respect of [ 17 (location of a horizontal axis 0) ] excitation of the solid-state-laser crystal 11.
[0013] Drawing 27 has shown the count result of the rise temperature 23 when inputting the excitation light of 10W into the solid-state-laser crystal of the above-mentioned active mirror method. Distance from the crystal center 23 where d and excitation light are irradiated in the distance from the excitation side 17 to a cooling surface 18 to the crystal side was set to r among drawing 27 , and the temperature change was set to T. In addition, in count, it is assumed that the energy of the abbreviation 1/3 of the absorbed excitation light 19 is changed into heat. Furthermore, in count, since the cooling effect from the excitation side 17 and the side 25 of the solid-state-laser crystal 11 is not taken into consideration, an actual temperature rise becomes lower than count. It turns out that temperature rises most in respect of solid-state-laser excitation so that more clearly than drawing 27 . In order that the cooling effect may decrease, this becomes a big demerit, so that it separates from a cooling surface. Although it is dependent on the parameter of a thermal configuration change of a crystal or a resonator in addition to temperature distribution about the quality of a beam, in this condition, it becomes difficult to perform a high increase in power further, maintaining the high quality of a beam.
[0014] The purpose of this invention controls the heat strain accompanying a high increase in power, and is to offer the creation method of the solid-state-laser crystal used for the solid-state-laser equipment and this which can take out a quality beam.

---

[Translation done.]

---

MEANS

---

[Means for Solving the Problem] A solid-state-laser crystal of this invention is characterized by dope concentration distribution of said laser activity ion changing to a crystal orientation of said solid-state-laser crystal in a solid-state-laser crystal of a disk configuration which has laser activity ion.
[0016] Moreover, a solid-state-laser crystal of this invention is characterized by dope concentration distribution of said laser activity ion increasing from an end face used as an excitation side of said solid-state-laser crystal continuously or gradually toward an end face used as a cooling surface in a solid-state-laser crystal of a disk configuration which has laser activity ion.
[0017] Moreover, gradual change of dope concentration distribution is characterized by being formed of cementation and two or more crystals with which dope concentration of laser activity ion differs being. Moreover, it is characterized by joining a crystal with which laser ion activity is not doped by excitation side of a solid-state-laser crystal. Moreover, it is characterized by two or more crystals with which concentration differs being joined by an optical contact or diffused junction. Moreover, it is characterized by laser activity ion being Nd or Yb.
[0018] The creation method of the solid-state-laser crystal of this invention by churning of a material solution is the creation method of a solid-state-laser crystal of pulling up a crystal, and a material solution agitates with a churning means with rotation raising, the activation segregation coefficient in the material solution of a solid-state-laser crystal brings close to the segregation coefficient of a proper, and it carries out carrying out the inclination of the laser activity ion concentration along a crystal orientation as the feature, attaching solid-state seed crystal to the material solution which heated material powder of a solid-state-laser crystal, and material powder fused,
[0019] It carries out that the manufacturing installation of the solid-state-laser crystal of this invention by churning of a material solution is the solid-state-laser crystal manufacturing installation which pulls up a crystal, attaching solid-state seed crystal to the material solution which has a means heat material powder of a solid-state-laser crystal, and material powder fused, and rotating it, is equipped with a means agitate a material solution, brings the activation segregation coefficient in the material solution of a solid-state-laser crystal close to the segregation coefficient of a proper by churning, and carries out the inclination of the laser activity ion concentration along a crystal orientation as
[0020] the creation method of the solid state laser crystal using the crucible of different ion concentration be the creation method of a solid state laser crystal of pull up a crystal , attach solid-state seed crystal to the material solution which heated the material powder of a solid state laser crystal , and a material powder fused , and rotate it , attach seed crystal in order of a material solution with high laser activation ion concentration , and be characterize by to carry out the inclination of the laser activity ion concentration along a crystal orientation to two or more material solutions with which the concentration of laser activity ion differ .
[0021] The manufacturing installation of the solid-state-laser crystal using the crucible of different ion concentration is the manufacturing installation of a solid-state-laser crystal which pulls up a crystal, attaching solid-state seed crystal to the material solution which has a means heat material powder of a solid-state-laser crystal, and material powder fused, and rotating it, and is characterized by to have two or more material solutions with which the concentration of laser activity ion differs, and to have a means attach seed crystal in order of a material solution with high laser active substance concentration.
[0022] The creation method of the solid-state-laser crystal of a material solution which carries out the increment in ion concentration is the method of pulling up a crystal and creating a solid-state-laser crystal, makes the laser activity ion concentration in said material solution increase with time amount, and is characterized by to carry out the inclination of the laser activity ion concentration in accordance with shaft orientations, attaching solid-state seed crystal to a material solution which heated material powder of a solid-state-laser crystal, and material powder fused, and rotating it.
[0023] The manufacturing installation of the solid-state-laser crystal of a material solution which carries out the increment in ion concentration is the manufacturing installation which pulls up a crystal and creates a solid-state-laser crystal, has the means to which the laser activity ion in said material solution makes increase with time amount, and is characterize by to carry out the inclination of the laser activity ion concentration in accordance with shaft orientations, attach solid-state seed crystal to the material solution which has a means heat material powder of a solid-state-laser crystal, and material powder fused, and rotate it.
[0024] A creation method of a solid-state-laser crystal characterized by carrying out the inclination of the laser activity ion concentration in accordance with shaft orientations of a crystal by fusing a part of perimeter of a solid-state-laser crystal with uniform laser activity ion concentration with a heating means, and carrying out multiple-

times migration from one side to another side in accordance with shaft orientations of a solid-state-laser crystal with said heating means.

[0025] The manufacturing installation of the solid-state-laser crystal characterized by to carry out the inclination of the laser activity ion concentration in accordance with the shaft orientations of a crystal by having a heating means for fusing a part of perimeter of a solid-state-laser crystal with uniform laser activity ion concentration, and a means move a relative position of said heating means and solid-state-laser crystal to another side from one side along a crystal orientation of a solid-state-laser crystal, and carrying out melting of said heating means, and carrying out the multiple-times migration of the perimeter of a solid-state-laser crystal from one side to another side.

[0026] A creation method of a solid-state-laser crystal by heating of a sintered compact is characterized by carrying out melting of some powder sintered compacts of a solid-state-laser crystal material with which it is joined to solid-state seed crystal into which a crystal is grown up from a fused solid-state-laser solution, and laser activity ion concentration has inclination in shaft orientations partially with a heating means, and laser activity ion concentration carrying out inclination in accordance with shaft orientations of a crystal.

[0027] A manufacturing installation of a solid-state-laser crystal by heating of a sintered compact A powder sintered compact of a laser crystal material with which solid-state seed crystal for growing up a crystal from a fused solid-state-laser solution is combined, and laser activity ion concentration has inclination in shaft orientations, It is characterized by heating means for fusing said some of powder sintered compacts, and creating a solid-state-laser crystal in which was made to carry out melting of said powder sintered compact partially with said heating means, and laser activity ion concentration carried out inclination in accordance with shaft orientations of a crystal.

[0028] Solid-state-laser equipment of this invention Semiconductor laser as the excitation light source, and a solid-state-laser crystal of a disk configuration, In solid-state-laser equipment which equipped with a cooling means a resonator which resonates light which carried out incidence of said semiconductor laser light, and was generated from an excitation side which is one end face of said solid-state-laser crystal, and a cooling surface which is an other-end side of said solid-state-laser crystal Dope concentration of laser activity ion in said solid-state-laser crystal is characterized by using a solid-state-laser crystal which has inclination which increases from an excitation side to a cooling surface. Moreover, it is characterized by using a solid-state-laser crystal with inclination which increases from an excitation side in proportion to a square of distance of the thickness direction to a cooling surface toward an end face which turns into a cooling surface from an end face from which concentration of laser activity ion serves as an excitation side of said solid-state-laser crystal.

[0029] Solid-state-laser equipment of this invention Semiconductor laser as the excitation light source, and a solid-state-laser crystal of a disk configuration, In solid-state-laser equipment which equipped with a cooling means a resonator which resonates light which carried out incidence of said semiconductor laser light, and was generated from an excitation side which is one end face of said solid-state-laser crystal, and a cooling surface which is an other-end side of said solid-state-laser crystal It is characterized by contacting said cooling means to the crystal face where said dope concentration is high using a solid-state-laser crystal joined so that it might become the inclination with which said dope concentration increases two or more crystals with which dope concentration of laser activity ion differs to a cooling surface from an excitation side.

[0030] It is characterized by two or more crystals with which concentration differs being joined by an optical contact or diffused junction.

[0031] It is characterized by joining a crystal with which laser ion activity is not doped by excitation side of a solid-state-laser crystal.

[0032]

[Embodiment of the Invention] The solid-state-laser crystal and the creation method of this invention, a manufacturing installation, and the solid-state-laser equipment using a solid-state-laser crystal are explained to details with reference to a drawing.

[0033] **** of the solid-state-laser equipment used by introduction this invention -- with reference to ******, it explains just. Drawing 1 is drawing showing the whole solid-state-laser equipment configuration used in the example of this invention. Solid-state-laser equipment has the output mirror 14 for taking out the condensing optical system 13 for condensing the semiconductor laser 16 for exciting the solid-state-laser crystal 11, and the excitation light 19 into the solid-state-laser crystal 11 and the excitation light reflex mirror 15, the heat sink 12 that cools the solid-state-laser crystal 11, and the solid-state-laser light 20. The nonreflective coat and the high reflective coat are given to the excitation side 17 and cooling surface 18 of the solid-state-laser crystal 11 to the wavelength of the excitation light 19 and the solid-state-laser light 14, respectively.

[0034] Next, actuation of the solid-state-laser equipment of drawing 1 is explained. The excitation light 19 outputted from semiconductor laser 16 is irradiated during the solid-state-laser crystal 11 from the condensing optical system 13. The excitation light 19 is turned up with the high reflective film of the cooling surface 18 of the solid-state-laser crystal 11, and carries out incidence to the excitation light reflex mirror 15. When turned up by the excitation light reflex mirror 15, incidence of the excitation light 19 is again carried out to the solid-state-laser crystal 11. Thereby, 99% of energy of the excitation light 19 is absorbed by the solid-state-laser crystal 11. A part is changed into heat and, as for the light absorbed by the solid-state-laser crystal 11, a part is outputted as a solid-state-laser light 20 which is the wavelength of 1064nm.

[0035] Next, the 1st example of the solid-state-laser crystal of this invention is explained. The 1st example of a solid-state-laser crystal is 4mm in the diameter of 6mm, and thickness, and the concentration of laser activity ion is

the crystal of Nd:YAG which increased in the thickness direction in proportion to distance like drawing 2 . In this example, the laser activity ion concentration in the excitation side 17 and a cooling surface 18 is 0.1 and 1.3atm%, respectively. The wavelength of the semiconductor laser light by this crystal is 880nm and output 10W, and is absorbed during a crystal of 99% of energy by going and coming back to under the crystal of this example two times.

[0036] Next, the effect when using the 1st example of the solid-state-laser crystal of this invention is explained. Drawing 3 plots the rate of the excitation light 19 absorbed during the solid-state-laser crystal 11 in the example of this invention from the excitation side 17 to shaft orientations between cooling surfaces 18. In addition, the rate when dividing the solid-state-laser crystal 11 into 16 in the thickness direction has shown the amount 22 of excitation light absorption. As the crystal of the 1st example, by the cooling surface 18 side, since the concentration of laser activity ion is high, the excitation absorption of light is large at a cooling surface 18 side, and since pyrexia becomes large, efficient cooling in a cooling surface is attained.

[0037] Drawing 4 is the result of calculating the temperature distribution in the crystal of the 1st example of a solid-state-laser crystal. Since the amount of excitation absorption of light becomes large near the cooling surface, while the peak of a temperature rise moves to a cooling surface side, it turns out that a rise value is held down by 26 or less degrees. In addition, also in this count, since the cooling effect from the excitation side 17 and the side 25 of the solid-state-laser crystal 11 is not taken into consideration, a temperature rise will be controlled further in fact.

[0038] Next, the 2nd example of the solid-state-laser crystal of this invention is explained. If it is made to increase more than the concentration in the second half of a 1atm% base in Nd:YAG shown in the 1st example of a solid-state-laser crystal, since the fall of a top level life will be produced, there is a limit in making concentration of activity ion high more than this. Therefore, the thickness of about 4mm is needed as thickness. On the other hand, ITTORIBIUMU which is the 2nd example of a solid-state-laser crystal: In YAG (Yb:YAG), the dope of activity ion is possible, without producing the fall of a top level life to 20atm%.

[0039] Drawing 5 expresses concentration 21 distribution of the laser activity ion under crystal at the time of changing to a Nd:YAG crystal and using a Yb:YAG crystal. In Yb:YAG, since a high concentration dope is attained compared with Nd:YAG, 99% of energy of excitation light will be absorbed by going and coming back to under a crystal with a thickness of 1.5mm two times.

[0040] Drawing 6 expresses the rise temperature distribution at the time of using the above-mentioned solid-state-laser crystal. Since thickness can be made thin in Yb:YAG, much more cooling effect from a cooling surface will be acquired, and the peak of rise temperature will be controlled by about 24.7 degrees.

[0041] In addition, although the solid-state-laser equipment of this invention described the arrangement which arranges the semiconductor laser 16 which is the excitation light 19 in a V character mold, and takes out the solid-state-laser light 20 perpendicularly to the solid-state-laser crystal 11, it can acquire the depressor effect of a temperature rise for the same configuration as the conventional example very much.

[0042] Next, the creation method of the solid-state-laser crystal of this invention and the manufacturing installation of a solid-state-laser crystal are stated to details using a drawing.

[0043] Drawing 7 is the block diagram of the 1st example which is the manufacturing installation of the solid-state-laser crystal of this invention, and differing from the manufacturing installation of the conventional solid-state-laser crystal is the point of having HANE 33 for churning for agitating the Nd:YAG solution 31 compulsorily. HANE 33 for churning is held at the rotating alumina rod 32, and agitates a Nd:YAG solution compulsorily by rotating with the alumina rod 32. By the conventional creation method, rotational speed and raising speed were slowly pulled up to about per hour 1mm per minute 20 times, respectively, and the solid-state-laser crystal which has uniform concentration in accordance with shaft orientations was raised so that concentration might become homogeneity to the shaft orientations of a crystal as much as possible. In this example, it is agitating the solution of Nd:YAG for rotational speed and raising speed compulsorily with a churning means like the creation method of the conventional solid-state-laser crystal, and the effective segregation coefficient to YAG of Nd is brought close to the segregation coefficient of a proper, and it becomes raisable [ the laser crystal which has a steep concentration gradient compared with the conventional training method ].

[0044] In this example, although how to rotate HANE for churning which is a compulsory churning means with the alumina rod 32 was explained, it is also possible to establish a driving means independently and to perform compulsory churning. Moreover, in this example, training of the laser crystal which has a steep concentration gradient, without using a churning means by being referred to as about per hour 1.5-2.5mm is also possible by making rotational speed and raising speed quicker than the creation method of the conventional solid-state-laser crystal.

[0045] Drawing 8 expresses distribution of the activity ion concentration 34 under solid-state-laser crystal when creating using the manufacturing installation of the solid-state-laser crystal by this invention. The length of a crystal is expressed with the relative value and the relative length 1 is equivalent to seed crystal side 38. Concentration is expressed with the relative value to the laser activity ion concentration in the Nd:YAG solution 31. A concentration gradient becomes steep as it goes to seed crystal side 38, so that more clearly than drawing 8 . Creation of a solid-state-laser crystal with a free concentration gradient is attained by changing the laser activity ion concentration in the Nd:YAG solution 31 so that clearly also from expressing the concentration of a crystal with relative concentration. moreover, the inclination a35 out of the created Nd:YAG crystal 27, inclination b36, and inclination c37 -- creation of a solid-state-laser crystal with a free concentration gradient is attained by starting

each portion.
[0046] Next, the creation method of the solid-state-laser crystal of this invention and the 2nd example of a manufacturing installation are described.
[0047] Drawing 9 is the block diagram of the 2nd example of the manufacturing installation of a solid-state-laser crystal, and has the crystal migration device 39 for moving in order the crucible 29 made from Ir and solid-state-laser crystal containing four kinds of solutions a40 with which laser activity ion concentration differs, a solution b41, a solution c42, and a solution d43 to a solution a40 - a solution d43. Laser activity ion concentration is set up so that it may become low, as it is the highest with a solution a40 and goes to a solution d43.
[0048] By the creation method of the solid-state-laser crystal of this example, a crystal is first grown up in a solution a40. When the desired length is reached, the Nd:YAG crystal 27 is moved to a solution b41 according to the crystal migration device 39, and a crystal is grown up again. Even a solution d43 repeats this. Thereby, creation of the crystal which has inclination in the length direction of a crystal is attained.
[0049] Drawing 10 expresses distribution of the laser activity ion concentration 48 under solid-state-laser crystal by the creation method of the solid-state-laser crystal of this example. Inclination a44, inclination b45, inclination c46, and inclination d47 are concentration gradients created in the solution a40, the solution b41, the solution c42, and the solution d43, respectively. Although it is difficult completely linear to make inclination, the depressor effect of temperature rise sufficient also as a solid-state-laser crystal with inclination like drawing 10 can be acquired. Moreover, by increasing the class of solution with which concentration differs, creation of a crystal with a more uniform concentration gradient is attained, and it is **.
[0050] In this example, although how to move a solid-state-laser crystal was explained, even if it moves a solution, creation of a crystal is possible.
[0051] Next, the creation method of the solid-state-laser crystal of this invention and the 3rd example of a manufacturing installation are described.
[0052] drawing 11 — the block diagram of the manufacturing installation of a solid-state-laser crystal — it is — the inside of the Nd:YAG solution 31 — a laser active substance — a raw material — Nd 2O3 The laser active substance inlet 49 for pouring in powder is formed.
[0053] Nd 2O3 which is the raw material powder of a laser active substance in the crucible 29 made from Ir first in the creation method of the solid-state-laser crystal by this example aluminum 2O3 to remove and Y2O3 Only powder is introduced and the YAG crystal with which a laser active substance is not contained is grown up. Then, it is Nd 2O3 from the laser active substance inlet 49 in time amount. Powder is poured in. By being able to make the laser activity ion concentration in the Nd:YAG solution 31 increase with time amount, and changing the injection rate and impregnation time amount of a laser active substance by this method, concentration is low at a seed crystal side, and it becomes possible to grow up a crystal with the concentration gradient which becomes so high that it separates.
[0054] Next, the creation method of the solid-state-laser crystal of this invention and the 4th example of a manufacturing installation are described.
[0055] In the manufacturing installation of the laser crystal in drawing 12 , the solid-state-laser crystal 50 with uniform concentration is held between the movable heaters 50 in accordance with the shaft orientations of a crystal, and a heater 50 moves to the right from the left, heating some crystals and making the zone of melting. By repeating such an activity, Nd3+ which is laser activity ion will move to right-hand side gradually.
[0056] Drawing 13 expresses distribution of the laser activity ion concentration under solid-state-laser crystal when using the creation method of the above-mentioned laser crystal. Concentration is expressed with the relative value to the concentration of the laser activity ion of the early Nd:YAG crystal 51, and early concentration is equivalent to a curve a52. Migration of a heater 50 is changed and concentration distribution of laser activity ion changes with ****** from a curve b53 to a curve d55. By this creation method, the creation method of a crystal with a still steeper concentration gradient becomes possible by the difference in the concentration of the crystal used in early stages, and the count of migration of a heater 50.
[0057] Next, the creation method of the solid-state-laser crystal of this invention and the 5th example of a manufacturing installation are described.
[0058] When drawing 14 is referred to, the manufacturing installation of the solid-state-laser crystal of this invention is the YAG seed crystal 26 held at the alumina rod 56 and aluminum 2O3 used as the raw material of Nd:YAG, Y2 O3, and Nd 2O3. It has the infrared generator 59 for generating the infrared radiation 60 for carrying out heating melting of some of Nd:YAG sintered compacts 58 which made the powder of a high grade sinter, and Nd:YAG sintered compacts 58. Beforehand, in the concentration of Nd 2O3 used as the raw material of laser activity ion, the Nd:YAG sintered compact 58 is created so that it may have inclination in shaft orientations. The infrared generator 59 has the migration device 61 for moving up and down while revolving around the Nd:YAG sintered compact 59.
[0059] Setting to this creation method, heating and carrying out melting of some Nd:YAG sintered compacts 58, from the YAG seed crystal 26 on a drawing, it rotates to down and the infrared generator 59 moves to it. Thereby, from the YAG seed crystal 26 side, whether it is the crystal of the Nd:YAG sintered compact 58 starts gradually, and a solid-state-laser crystal with the concentration gradient of the laser activity ion according to the concentration gradient of the laser activity ion in the Nd:YAG sintered compact 58 is created. In this creation method, creation of a solid-state-laser crystal with a free concentration gradient is attained by changing the concentration of the laser activity ion contained in the Nd:YAG sintered compact 58.
[0060] Next, the 2nd example of the solid-state-laser crystal of this invention is explained to details with reference

to a drawing.
[0061] The concentration 62 of laser activity ion is made to increase from an excitation side in proportion to the square of the distance of the thickness direction to a cooling surface like drawing 15 in this example to a Nd:YAG solid-state-laser crystal with a diameter [ of 6mm ], and a thickness of 4mm. The activity ion concentration in the excitation side 17 and a cooling surface 18 is 0.2 and 1.4atm%, respectively. By having such concentration distribution shows that the amount 63 of excitation light absorption absorbed during a solid-state-laser crystal becomes large by the cooling surface side further compared with the crystal which has a linear concentration gradient as shown in drawing 16 .
[0062] Drawing 17 expresses the count result of the rise temperature when exciting a solid-state-laser crystal by the semiconductor laser of 10W. While the peak of rise temperature moves to a cooling surface side compared with the example of drawing 2 of a solid-state-laser crystal, peak value becomes possible [ controlling further ] compared with the case where it has the linear concentration gradient of 23.4 degrees and drawing 2 .
[0063] Next, the 3rd example of the laser crystal of this invention is explained to details with reference to a drawing.

[0064] Drawing 18 (a) expresses the side elevation of the solid-state-laser crystal of this invention, and drawing 18 (b) expresses concentration distribution of laser activity ion. As for the solid-state-laser crystal of this invention, reference of drawing 18 joins the crystal of four different sheets of laser activity ion concentration. It is joined to order with low concentration from the crystal a65 with the lowest concentration, and a crystal a65 is arranged in the excitation side 17, and the crystal d68 is arranged in the cooling surface 18.
[0065] Drawing 19 expresses the amount 69 of excitation absorption of light, and an absorbed amount becomes large as it goes to a crystal d68 from a crystal a65. Furthermore, if the number of partitions of a crystal is increased, the example of drawing 2 will be approached.
[0066] Drawing 20 expresses the count result of the rise temperature when exciting a solid-state-laser crystal by the semiconductor laser of 10W. The peak value of rise temperature is 28.3 degrees, and the depressor effect of a temperature rise as well as the example of drawing 2 is acquired.
[0067] Next, how to create the 3rd example of a solid-state-laser crystal is described.
[0068] 1mm in the diameter of 6mm, and thickness, and laser activity ion concentration — respectively — 0.35 and 0. — it is 7, 1.05, and 1.4atm% and what ground the both ends of the crystal which is four sheets whose crystallographics axis corresponded at lambda/10, and parallelism 1 second is joined by the optical contact. It enables this to create the solid-state-laser crystal which the optical loss in a plane of composition hardly produces.

[0069] In this example, although only the creation method of the crystal by the optical contact was described, creation by diffused junction is also possible.
[0070] Next, the 4th example of the solid-state-laser crystal of this invention is explained to details with reference to a drawing.
[0071] Drawing 21 (a) expresses the side elevation of the solid-state-laser crystal of this invention, and drawing 21 (b) expresses concentration distribution of laser activity ion. As for the solid-state-laser crystal of this invention, reference of drawing 21 joins the crystal of two sheets of the crystal b with inclination with linear crystal a70 and concentration gradient by which laser activity ion is not doped. The plane of composition of Crystal b is a field where concentration is low, and another field is arranged in the cooling surface.
[0072] Drawing 22 expresses the rate 73 of the amount of excitation absorption of light, in a crystal a70, the excitation absorption of light does not happen but excitation light is absorbed as a crystal b74.
[0073] Drawing 23 expresses the count result of the rise temperature when exciting a solid-state-laser crystal by the semiconductor laser of 10W. The peak value of rise temperature is 25.8 and the temperature depressor effect of 0.2 is acquired compared with the example shown in drawing 2 . In fact, since the cooling effect from the side is acquired, in this example it is twice whose surface area of the side of this compared with the example of drawing 2 , the depressor effect of temperature is acquired more. Furthermore, as a crystal a70, since the excitation absorption of light does not happen, the increase of the thickness of a crystal, and in order that [ even if it carries out, ] the depressor effect of a temperature rise may not decrease, the strong rise effect over a mechanical strain is acquired. Moreover, in the 4th example, although dope concentration serves as a straight line, it is not restricted to this, and it can use also for the solid-state-laser crystal stated in the 1st of a solid-state-laser crystal - the 3rd example.
[0074] In addition, Nd or Yb can be used for the 2nd of a solid-state-laser crystal - the 4th example as laser activity ion.

---

[Translation done.]

---

## DESCRIPTION OF DRAWINGS

---

[Brief Description of the Drawings]
[Drawing 1] It is drawing showing the whole solid-state-laser equipment configuration used for this invention.
[Drawing 2] It is drawing showing concentration distribution of the laser activity ion in the Nd:YAG crystal which is the 1st example of the solid-state-laser crystal of this invention.
[Drawing 3] It is drawing showing the rate of the amount of excitation absorption of light in the Nd:YAG crystal which is the 1st example of the solid-state-laser crystal of this invention.
[Drawing 4] It is drawing showing the rise temperature distribution in the Nd:YAG crystal which is the 1st example of the solid-state-laser crystal of this invention.
[Drawing 5] It is drawing showing concentration distribution of the laser activity ion in the Yb:YAG crystal which is the 1st example of the solid-state-laser crystal of this invention.
[Drawing 6] It is drawing showing the rise temperature distribution in the Yb:YAG crystal which is the 1st example of the solid-state-laser crystal of this invention.
[Drawing 7] It is drawing for explaining the 1st example of the manufacturing installation of the solid-state-laser crystal of this invention.
[Drawing 8] It is drawing showing the laser activity ion concentration in the Nd:YAG crystal created according to the 1st example of the creation method of the solid-state-laser crystal of this invention.
[Drawing 9] It is drawing for explaining the 2nd example of the manufacturing installation of the solid-state-laser crystal of this invention.
[Drawing 10] It is drawing showing the laser activity ion concentration in the Nd:YAG crystal created according to the 2nd example of the creation method of the solid-state-laser crystal of this invention.
[Drawing 11] It is drawing for explaining the 3rd example of the manufacturing installation of the solid-state-laser crystal of this invention.
[Drawing 12] It is drawing for explaining the 4th example of the manufacturing installation of the solid-state-laser crystal of this invention.
[Drawing 13] It is drawing showing the laser activity ion concentration in the Nd:YAG crystal created according to the 4th example of the creation method of the solid-state-laser crystal of this invention.
[Drawing 14] It is drawing for explaining the 5th example of the manufacturing installation of the solid-state-laser crystal of this invention.
[Drawing 15] It is drawing showing concentration distribution of the laser activity ion in the Nd:YAG crystal which is the 2nd example of the solid-state-laser crystal of this invention.
[Drawing 16] It is drawing showing the rate of the amount of excitation absorption of light in the Nd:YAG crystal which is the 2nd example of the solid-state-laser crystal of this invention.
[Drawing 17] It is drawing showing the rise temperature distribution in the Nd:YAG crystal which is the 2nd example of the solid-state-laser crystal of this invention.
[Drawing 18] It is drawing showing concentration distribution of drawing for explaining the 3rd example of the solid-state-laser crystal of this invention and laser activity ion.
[Drawing 19] It is drawing showing the rate of the amount of excitation absorption of light in the Nd:YAG crystal which is the 3rd example of the solid-state-laser crystal of this invention.
[Drawing 20] It is drawing showing the rise temperature distribution in the Nd:YAG crystal which is the 3rd example of the solid-state-laser crystal of this invention.
[Drawing 21] They are drawing for explaining the 4th example of the solid-state-laser crystal of this invention, and drawing showing concentration distribution of laser activity ion.
[Drawing 22] It is drawing showing the rate of the amount of excitation absorption of light in the Nd:YAG crystal which is the 4th example of the solid-state-laser crystal of this invention.
[Drawing 23] It is drawing showing the rise temperature distribution in the Nd:YAG crystal which is the 4th example of the solid-state-laser crystal of this invention.
[Drawing 24] It is drawing showing the conventional solid-state-laser equipment whole configuration.
[Drawing 25] It is drawing for explaining the manufacturing installation of the conventional solid-state-laser crystal.
[Drawing 26] It is drawing of the amount of excitation light absorption in the solid-state-laser crystal of conventional solid-state-laser equipment shown comparatively.
[Drawing 27] It is drawing showing the rise temperature distribution in the laser crystal of conventional solid-state-laser equipment.

[Description of Notations]
10 Reflecting Mirror
11 Solid-State-Laser Crystal
12 Heat Sink
13 Condensing Optical System
14 Output Mirror
15 Excitation Light Reflex Mirror
16 Semiconductor Laser
17 Excitation Side
18 Cooling Surface
19 Excitation Light
20 Solid-State-Laser Light
21 Laser Activity Ion Concentration
22 The Amount of Excitation Light Absorption
23 Crystal Center
24 Rise Temperature
25 Crystal Side
26 YAG Seed Crystal
27 Nd:YAG Crystal
28 Alumina Heat Insulator
29 Crucible made from Ir
30 Coil for Induction Heating
31 Nd:YAG Solution
32 Alumina Rod
33 HANE for Churning
34 Laser Activity Ion Concentration
35 Inclination A
36 Inclination B
37 Inclination C
38 Seed Crystal Side
39 Crystal Migration Device
40 Solution A
41 Solution B
42 Solution C
43 Solution D
44 Inclination A
45 Inclination B
46 Inclination C
47 Inclination D
48 Laser Activity Ion Concentration
49 Laser Active Substance Inlet
50 Heater
51 Nd:YAG Crystal
52 Curve A
53 Curve B
54 Curve C
55 Curve D
58 Nd:YAG Sintered Compact
59 Infrared Generator
60 Infrared Radiation
61 Infrared Generator Migration Device
62 Laser Activity Ion Concentration
63 The Amount of Excitation Light Absorption
64 Laser Activity Ion Concentration
65 Crystal A
66 Crystal B
67 Crystal C
68 Crystal D
69 The Amount of Excitation Light Absorption
70 Crystal A
71 Crystal B
72 Laser Activity Ion Concentration
73 The Amount of Excitation Light Absorption

---

[Translation done.]

(19)日本国特許庁（ＪＰ）　(12)特　許　公　報（Ｂ２）　(11)特許番号
特許第3266071号
(P3266071)
(45)発行日　平成14年３月18日(2002.3.18)　(24)登録日　平成14年１月11日(2002.1.11)

| (51)Int.Cl.7 | 識別記号 | ＦＩ |
|---|---|---|
| Ｈ０１Ｓ　3/16 | | Ｈ０１Ｓ　3/16 |
| Ｃ３０Ｂ　15/04 | | Ｃ３０Ｂ　15/04 |

請求項の数20(全 13 頁)

(21)出願番号　特願平9－279275
(22)出願日　平成９年10月14日(1997.10.14)
(65)公開番号　特開平11－121855
(43)公開日　平成11年４月30日(1999.4.30)
審査請求日　平成９年10月14日(1997.10.14)
(73)特許権者　000004237
日本電気株式会社
東京都港区芝五丁目７番１号
(72)発明者　斎藤　隆志
東京都港区芝五丁目７番１号　日本電気株式会社内
(74)代理人　100082935
弁理士　京本　直樹　（外２名）
審査官　河原　正
(56)参考文献　特開　昭50－132891（ＪＰ，Ａ）
特開　平５－152646（ＪＰ，Ａ）
特開　平６－140696（ＪＰ，Ａ）
特公　昭46－32404（ＪＰ，Ｂ１）
最終頁に続く

# (54)【発明の名称】固体レーザ結晶とその作成方法及び固体レーザ装置



(57)【特許請求の範囲】

【請求項１】レーザ活性イオンを有するディスク形状の固体レーザ結晶において、前記固体レーザ結晶の励起面となる端面から冷却面となる端面に向かって前記レーザ活性イオンのドープ濃度分布が連続的又は段階的に増加していることを特徴とする固体レーザ結晶。

【請求項２】前記ドープ濃度分布の連続的な変化が直線又は曲線であることを特徴とする請求項１記載の固体レーザ結晶。

【請求項３】前記ドープ濃度分布の段階的な変化が直線又は曲線であることを特徴とする請求項１記載の固体レーザ結晶。

【請求項４】レーザ活性イオンを有するディスク形状の固体レーザ結晶において、レーザ活性イオンの濃度が前記固体レーザ結晶の励起面となる端面から冷却面となる端面に向かって、励起面から冷却面までの厚さ方向の距離の２乗に比例して増加する勾配を持つことを特徴とする固体レーザ結晶。



【請求項５】前記ドープ濃度分布の段階的な変化がレーザ活性イオンのドープ濃度が異なる複数個の結晶を接合により形成されていることを特徴とする請求項１又は３記載の固体レーザ結晶。

【請求項６】前記濃度の異なる複数個の結晶がオプティカルコンタクトあるいは拡散接合により接合されていることを特徴とする請求項５記載の固体レーザ結晶。

【請求項７】前記固体レーザ結晶の励起面にレーザイオン活性のドープされていない結晶を接合したことを特徴とする請求項１記載の固体レーザ結晶。

【請求項８】前記レーザ活性イオンはNd又はＹｂであることを特徴とする請求項７記載の固体レーザ結晶。

【請求項９】固体レーザ結晶の材料粉末を加熱し、材料粉末が溶融した材料溶液に固体種結晶を付け、回転させながら結晶を引き上げて固体レーザ結晶を作成する方法であって、前記材料溶液中のレーザ活性イオン濃度を時間とともに増加させ、レーザ活性イオンの濃度を結晶軸方向に沿って勾配させることを特徴とする固体レーザ結晶の作成方法。

【請求項１０】固体レーザ結晶の材料粉末を加熱する手段を有し、材料粉末が溶融した材料溶液に固体種結晶を付け、回転させながら結晶を引き上げて固体レーザ結晶を作成する製造装置であって、前記材料溶液中のレーザ活性イオンを時間とともに増加させる手段を有し、レーザ活性イオンの濃度を結晶軸方向に沿って勾配させることを特徴とする固体レーザ結晶の製造装置。

【請求項１１】レーザ活性イオンの濃度が均一な固体レーザ結晶の周囲の一部を加熱手段により溶融し、前記加熱手段により固体レーザ結晶周囲を軸方向に沿って一方から他方へ複数回移動させることにより、レーザ活性イオンの濃度を結晶の軸方向に沿って勾配させることを特徴とする固体レーザ結晶の作成方法。

【請求項１２】レーザ活性イオンの濃度が均一な固体レーザ結晶の周囲の一部を溶融するための加熱手段と、前記加熱手段と前記固体レーザ結晶との相対位置を固体レーザ結晶の結晶軸方向に沿って一方から他方へ移動させる手段を有し、前記加熱手段により固体レーザ結晶の周囲を溶融させ、かつ、一方から他方へ複数回移動させることにより、レーザ活性イオン濃度を結晶軸方向に沿って勾配させることを特徴とする固体レーザ結晶の製造装置。

【請求項１３】溶融した固体レーザ溶液から結晶を成長させる固体種結晶に接合されレーザ活性イオンの濃度が結晶軸方向に勾配を持つ固体レーザ結晶材料の粉末焼結体の一部を加熱手段により部分的に溶融させて、レーザ活性イオン濃度を結晶軸方向に沿って勾配させることを特徴とする固体レーザ結晶の作成方法。

【請求項１４】溶融した固体レーザ溶液から結晶を成長させるための固体種結晶と、前記固体種結晶に結合されレーザ活性イオンの濃度が結晶軸方向に勾配を持つレーザ結晶材料の粉末焼結体と、前記粉末焼結体の一部を溶融するための加熱手段とを有し、前記粉末焼結体を前記加熱手段により部分的に溶融させて、レーザ活性イオン濃度が結晶の軸方向に沿って勾配した固体レーザ結晶を作成することを特徴とする固体レーザ結晶の製造装置。

【請求項１５】励起光源としての半導体レーザと、ディスク形状の固体レーザ結晶と、前記固体レーザ結晶の一方の端面である励起面より前記半導体レーザ光を入射して発生した光を共振させる共振器と、前記固体レーザ結晶の他方の端面である冷却面に冷却手段を備えた固体レーザ装置において、前記固体レーザ結晶内のレーザ活性イオンのドープ濃度が、励起面から冷却面へ増加する勾配を有する固体レーザ結晶を用いたことを特徴とする固体レーザ装置。

【請求項１６】レーザ活性イオンのドープ濃度が励起面から冷却面へ増加する濃度勾配が連続的であり、直線状または曲線状であることを特徴とする請求項１５記載の固体レーザ装置。

【請求項１７】レーザ活性イオンの濃度が前記固体レーザ結晶の励起面となる端面から冷却面となる端面に向かって、励起面から冷却面までの厚さ方向の距離の２乗に比例して増加する勾配を持つ固体レーザ結晶を用いたことを特徴とする請求項１５記載の固体レーザ装置。

【請求項１８】励起光源としての半導体レーザと、ディスク形状の固体レーザ結晶と、前記固体レーザ結晶の一方の端面である励起面より前記半導体レーザ光を入射して発生した光を共振させる共振器と、前記固体レーザ結晶の他方の端面である冷却面に冷却手段を備えた固体レーザ装置において、レーザ活性イオンのドープ濃度が異なる複数個の結晶を前記ドープ濃度が励起面から冷却面へ増加する勾配となるように接合した固体レーザ結晶を用い、前記ドープ濃度の高い結晶面に前記冷却手段を接触させていることを特徴とする固体レーザ装置。

【請求項１９】前記濃度の異なる複数個の結晶がオプティカルコンタクトあるいは拡散接合により接合されたことを特徴とする請求項１８記載の固体レーザ装置。

【請求項２０】固体レーザ結晶の励起面にレーザイオン活性のドープされていない結晶を接合したことを特徴とする請求項１５記載の固体レーザ装置。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、半導体レーザを励起源とする固体レーザ装置に関し、固体レーザ結晶とこれを用いた固体レーザ装置及び固体レーザ結晶の作成方法及びその製造装置に関する。

【０００２】

【従来の技術】近年の高出力半導体レーザの技術進歩により、従来の放電ランプ励起に変わる半導体レーザ励起固体レーザの開発が活発化している。半導体レーザ励起は、放電ランプ励起に比べて、高効率、高ビーム品質、小型、長寿命などの特徴を有する。半導体レーザ励起固体レーザの高出力化は、基本的には、入力する半導体レーザ光の強度の増加によって達成できる。しかしながら、高出力化と高ビーム品質は、トレードオフの関係にあり、入力する半導体レーザ光を増加させるにつれて、結晶内の温度上昇に伴う屈折率分布及び熱ひずみの増加により、ビーム品質が劣化するという問題が生じる。

【０００３】これを解決する１つの方策として、薄いディスク型レーザ結晶を端面励起し、裏面より端面冷却するアクティブミラー方式が提案されている。アクティブミラー方式の半導体レーザ励起固体レーザについては、例えば「レーザ研究、第２４巻、５９頁から６５頁」に

詳細に記述されている。

【０００４】図２４は、従来の固体レーザ装置の一例を示す図である。固体レーザ結晶１１は、直径６ｍｍ、厚さ２ｍｍのディスク形状であり、イットリウム・アルミニウム・ガーネット（YAG）の母材に、１．４ａｔｍ％の濃度でレーザ活性イオンである$Nd^{3+}$がほぼ均一ドープされている。励起光１９及び固体レーザ光２０の波長に対して、固体レーザ結晶１１の励起面１７には無反射コーティングが、冷却面１８には高反射コーティングが施されている。半導体レーザ１６から出力された波長８８０ｎｍの励起光１９は、厚さ２ｍｍの固体レーザ結晶１１中を１往復することにより９０％のエネルギーが固体レーザ結晶中に吸収される。

【０００５】次に、従来の固体レーザ結晶を作成する方法について、ネオジウム：ＹＡＧ（Ｎｄ：ＹＡＧ）結晶の場合を例にあげて説明する。

【０００６】図２５は、従来の固体レーザ結晶の作成方法を説明するための図であり、引き上げ法による結晶の育成炉を示してある。引き上げ法では、まずＩｒ製るつぼ２９の中に、Ｎｄ：ＹＡＧの原料となる$Al_2O_3$、$Y_2O_3$及び$Nd_2O_3$の高純度の粉末を入れ、誘導加熱用コイル３１により、粉末を溶かし、Ｎｄ：ＹＡＧ溶液３１を生成させ、アルミナ棒３２の先端に保持した、ＹＡＧ種結晶２６をＮｄ：ＹＡＧ溶液３１の中につけ、ゆっくり回転させながら引き上げる。

【０００７】レーザ活性イオンと母材の結晶には、物質固有の偏析係数が存在する。偏析係数が１の場合、結晶の軸方向にそった濃度分布は生じないが、ＮｄのＹＡＧに対する偏析係数は１以下であり、活性イオン濃度は引き上げるにつれて薄くなるような分布を持つ。このため従来の育成方法では、出来る限り結晶の軸方向に濃度が均一になるように、回転速度及び引き上げ速度をそれぞれ、毎分２０回、毎時１ｍｍ程度に設定し、軸方向に沿って均一な濃度を持つ固体レーザ結晶を育成していた。その後、所望の大きさに切断し、研磨後に無反射、高反射コーティングを施し、固体レーザ結晶を作成していた。

【０００８】次に従来の固体レーザ装置の動作について、図２４を参照して説明する。

【０００９】半導体レーザ１６より出力した励起光１９は、集光光学系１３を通して、固体レーザ結晶に入力する。励起光１９は、固体レーザ結晶１１の冷却面１８で折り返されることにより、ほぼ、９０％以上のエネルギーが固体レーザ結晶１１に吸収される。固体レーザ結晶１１に吸収された光の一部は熱に変換され、一部が波長１０６４ｎｍの固体レーザ光２０として、出力鏡１４より出力される。

【００１０】前述のアクティブミラー方式では、理想的には、結晶内の温度分布が厚み方向に一次元に分布するために、レーザ発振の光軸と温度勾配ベクトルが平行となり、熱レンズ効果が抑制される。更に、発熱位置と冷却面の距離が短くとれるために、効率的な冷却が可能となる。

【００１１】

【発明が解決しようとする課題】問題点は、レーザ結晶及び励起光の大きさが有限であるために、結晶表面の励起光の集光部をピークとして楕円状に温度勾配が生じるために、前述した熱レンズの抑制効果が減少してしまう。更に、従来のレーザ結晶では、母材にドープされるレーザ活性イオン濃度が一定であるために、励起光の大部分が、レーザ結晶表面で吸収されてしまい、レーザ結晶表面の温度が上昇しやすいという欠点がある。

【００１２】図２６は、結晶の厚みを４ｍｍ、活性イオン濃度を１．４ａｔｍ％とし、励起光の９９％が結晶中に吸収されるように設定した固体レーザ結晶の、結晶中への励起光の吸収量２２を示した図である。なお、吸収量は、結晶を厚み（４ｍｍ）方向に１６分割したときの割合で表している。図２６より明らかなように、結晶の励起面で大部分の励起光が吸収されることになる。この結果、結晶内の温度上昇は、固体レーザ結晶１１の励起面１７（横軸０の位置）で最も高くなる。

【００１３】図２７は、前述のアクティブミラー方式の固体レーザ結晶に１０Ｗの励起光を入力したときの、上昇温度２３の計算結果を示してある。図２７中、励起面１７から冷却面１８までの距離をｄ、励起光が照射される結晶中心２３から結晶側面までの距離をｒ、温度変化をＴとした。なお、計算では、吸収された励起光１９の約１／３のエネルギーが熱に変換されると仮定している。更に、計算では、固体レーザ結晶１１の励起面１７及び側面２５からの冷却効果を考慮していないため、実際の温度上昇は、計算よりも低くなる。図２７より明らかなように、固体レーザ励起面でもっとも温度が上昇することが判る。冷却面から離れるほど冷却効果は減少するために、このことは、大きなデメリットになる。ビームの品質に関しては、温度分布以外にも、結晶の熱的な形状変化や共振器のパラメータにも依存するが、この状態では、ビームの高品質を維持しながら、更に高出力化を行うことが困難になる。

【００１４】本発明の目的は、高出力化に伴う熱ひずみを抑制し、高品質なビームを取り出すことができる固体レーザ装置及びこれに用いる固体レーザ結晶の作成方法を提供することにある。

【００１５】

【課題を解決するための手段】本発明の固体レーザ結晶は、レーザ活性イオンを有するディスク形状の固体レーザ結晶において、前記固体レーザ結晶の結晶軸方向に前記レーザ活性イオンのドープ濃度分布が変化していることを特徴とする。

【００１６】また本発明の固体レーザ結晶は、レーザ活性イオンを有するディスク形状の固体レーザ結晶におい

て、前記固体レーザ結晶の励起面となる端面から冷却面となる端面に向かって前記レーザ活性イオンのドープ濃度分布が連続的又は段階的に増加していることを特徴とする。

【００１７】　またドープ濃度分布の段階的な変化がレーザ活性イオンのドープ濃度が異なる複数個の結晶を接合により形成されいてることを特徴とする。また固体レーザ結晶の励起面にレーザイオン活性のドープされていない結晶を接合したことを特徴とする。また濃度の異なる複数個の結晶がオプティカルコンタクトあるいは拡散接合により接合されていることを特徴とする。またレーザ活性イオンはＮｄ又はＹｂであることを特徴とする。

【００１８】材料溶液の撹拌による本発明の固体レーザ結晶の作成方法は、固体レーザ結晶の材料粉末を加熱し、材料粉末が溶融した材料溶液に固体種結晶を付け、回転させながら結晶を引き上げる固体レーザ結晶の作成方法であって、回転引き上げとともに材料溶液を撹拌手段により撹拌し、固体レーザ結晶の材料溶液における実行偏析係数を固有の偏析係数に近づけ、レーザ活性イオン濃度を結晶軸方向に沿って勾配させることを特徴とする。

【００１９】材料溶液の撹拌による本発明の固体レーザ結晶の製造装置は、固体レーザ結晶の材料粉末を加熱する手段を有し、材料粉末が溶融した材料溶液に固体種結晶を付け、回転させながら結晶を引き上げる固体レーザ結晶製造装置であって、材料溶液を撹拌する手段を備え、撹拌により固体レーザ結晶の材料溶液における実行偏析係数を固有の偏析係数に近づけ、レーザ活性イオン濃度を結晶軸方向に沿って勾配させることを特徴とする。

【００２０】異なるイオン濃度のるつぼを用いた固体レーザ結晶の作成方法は、固体レーザ結晶の材料粉末を加熱し、材料粉末が溶融した材料溶液に固体種結晶を付け、回転させながら結晶を引き上げる固体レーザ結晶の作成方法であって、レーザ活性イオンの濃度の異なる複数個の材料溶液に対し、レーザ活性化イオン濃度の高い材料溶液の順に種結晶をつけ、レーザ活性イオン濃度を結晶軸方向に沿って勾配させることを特徴とする。

【００２１】異なるイオン濃度のるつぼを用いた固体レーザ結晶の製造装置は、固体レーザ結晶の材料粉末を加熱する手段を有し、材料粉末が溶融した材料溶液に固体種結晶を付け、回転させながら結晶を引き上げる固体レーザ結晶の製造装置であって、レーザ活性イオンの濃度の異なる複数個の材料溶液を有し、レーザ活性物質濃度の高い材料溶液の順に種結晶をつける手段を有することを特徴とする。

【００２２】材料溶液のイオン濃度増加させる固体レーザ結晶の作成方法は、固体レーザ結晶の材料粉末を加熱し、材料粉末が溶融した材料溶液に固体種結晶を付け、回転させながら結晶を引き上げて固体レーザ結晶を作成する方法であって、前記材料溶液中のレーザ活性イオン濃度を時間とともに増加させ、レーザ活性イオン濃度を軸方向に沿って勾配させることを特徴とする。

【００２３】材料溶液のイオン濃度増加させる固体レーザ結晶の製造装置は、固体レーザ結晶の材料粉末を加熱する手段を有し、材料粉末が溶融した材料溶液に固体種結晶を付け、回転させながら結晶を引き上げて固体レーザ結晶を作成する製造装置であって、前記材料溶液中のレーザ活性イオンを時間とともに増加させる手段を有し、レーザ活性イオン濃度を軸方向に沿って勾配させることを特徴とする。

【００２４】レーザ活性イオン濃度が均一な固体レーザ結晶の周囲の一部を加熱手段により溶融し、前記加熱手段により固体レーザ結晶の軸方向に沿って一方から他方へ複数回移動させることにより、レーザ活性イオン濃度を結晶の軸方向に沿って勾配させることを特徴とする固体レーザ結晶の作成方法。

【００２５】レーザ活性イオン濃度が均一な固体レーザ結晶の周囲の一部を溶融するための加熱手段と、前記加熱手段と固体レーザ結晶との相対位置を固体レーザ結晶の結晶軸方向に沿って一方から他方へ移動させる手段を有し、前記加熱手段を固体レーザ結晶の周囲を溶融させ、かつ、一方から他方へ複数回移動させることにより、レーザ活性イオン濃度を結晶の軸方向に沿って勾配させることを特徴とする固体レーザ結晶の製造装置。

【００２６】焼結体の加熱による固体レーザ結晶の作成方法は、溶融した固体レーザ溶液から結晶を成長させる固体種結晶に接合されレーザ活性イオン濃度が軸方向に勾配を持つ固体レーザ結晶材料の粉末焼結体の一部を加熱手段により部分的に溶融させて、レーザ活性イオン濃度が結晶の軸方向に沿って勾配させることを特徴とする。

【００２７】焼結体の加熱による固体レーザ結晶の製造装置は、溶融した固体レーザ溶液から結晶を成長させるための固体種結晶が結合されレーザ活性イオン濃度が軸方向に勾配を持つレーザ結晶材料の粉末焼結体と、前記粉末焼結体の一部を溶融するための加熱手段と、前記粉末焼結体を前記加熱手段により部分的に溶融させて、レーザ活性イオン濃度が結晶の軸方向に沿って勾配した固体レーザ結晶を作成することを特徴とする。

【００２８】本発明の固体レーザ装置は、励起光源としての半導体レーザと、ディスク形状の固体レーザ結晶と、前記固体レーザ結晶の一方の端面である励起面より前記半導体レーザ光を入射して発生した光を共振させる共振器と、前記固体レーザ結晶の他方の端面である冷却面に冷却手段を備えた固体レーザ装置において、前記固体レーザ結晶内のレーザ活性イオンのドープ濃度が、励起面から冷却面へ増加する勾配を有する固体レーザ結晶を用いたことを特徴とする。またレーザ活性イオンの濃度が前記固体レーザ結晶の励起面となる端面から冷却面

となる端面に向かって、励起面から冷却面までの厚さ方向の距離の２乗に比例して増加する勾配を持つ固体レーザ結晶を用いたことを特徴とする。

【００２９】本発明の固体レーザ装置は、励起光源としての半導体レーザと、ディスク形状の固体レーザ結晶と、前記固体レーザ結晶の一方の端面である励起面より前記半導体レーザ光を入射して発生した光を共振させる共振器と、前記固体レーザ結晶の他方の端面である冷却面に冷却手段を備えた固体レーザ装置において、レーザ活性イオンのドーブ濃度が異なる複数個の結晶を前記ドーブ濃度が励起面から冷却面へ増加する勾配となるように接合した固体レーザ結晶を用い、前記ドーブ濃度の高い結晶面に前記冷却手段を接触させていることを特徴とする。

【００３０】濃度の異なる複数個の結晶がオプティカルコンタクトあるいは拡散接合により接合されたことを特徴とする。

【００３１】固体レーザ結晶の励起面にレーザイオン活性のドーブされていない結晶を接合したことを特徴とする。

【００３２】

【発明の実施の形態】本発明の固体レーザ結晶とその作成方法及び製造装置と固体レーザ結晶を用いた固体レーザ装置について図面を参照して詳細に説明する。

【００３３】初めに本発明で用いる固体レーザ装置の構成ついて図面を参照して説明する。図１は、本発明の実施例で用いた固体レーザ装置の全体構成を示す図である。固体レーザ装置は、固体レーザ結晶１１を励起するための半導体レーザ１６、励起光１９を固体レーザ結晶１１に集光するための集光光学系１３及び励起光反射鏡１５、固体レーザ結晶１１を冷却するヒートシンク１２、固体レーザ光２０を取り出すための出力鏡１４を有している。固体レーザ結晶１１の励起面１７及び冷却面１８には、それぞれ、励起光１９及び固体レーザ光１４の波長に対して無反射コート、及び高反射コートが施されている。

【００３４】次に図１の固体レーザ装置の動作について説明する。半導体レーザ１６より出力した励起光１９は、集光光学系１３より固体レーザ結晶１１中に照射される。励起光１９は、固体レーザ結晶１１の冷却面１８の高反射膜により折り返され、励起光反射鏡１５へ入射する。励起光１９は、励起光反射鏡１５に折り返されることにより、再び、固体レーザ結晶１１に入射する。これにより、励起光１９の９９％のエネルギーが固体レーザ結晶１１に吸収される。固体レーザ結晶１１に吸収された光は、一部は熱に変換され、一部が波長１０６４ｎｍの固体レーザ光２０として出力される。

【００３５】次に本発明の固体レーザ結晶の第１の実施例について説明する。固体レーザ結晶の第１の実施例は、直径６ｍｍ、厚さ４ｍｍであり、レーザ活性イオンの濃度が図２のように、厚さ方向に距離に比例して増加したＮｄ：ＹＡＧの結晶である。本実施例では、励起面１７、冷却面１８でのレーザ活性イオン濃度は、それぞれ、０．１、１．３ａｔｍ％である。この結晶による半導体レーザ光の波長は、８８０ｎｍ、出力１０Ｗであり、本実施例の結晶中を２往復することにより９９％のエネルギーが結晶中に吸収される。

【００３６】次に本発明の固体レーザ結晶の第１の実施例を用いたときの効果について説明する。図３は、本発明の実施例における固体レーザ結晶１１中に吸収された励起光１９の割合を、励起面１７から冷却面１８の間で軸方向にプロットしたものである。なお、励起光吸収量２２は、固体レーザ結晶１１を厚み方向に１６分割したときの割合で示してある。第１の実施例の結晶では、冷却面１８側でレーザ活性イオンの濃度が高いために、冷却面１８側で励起光の吸収が大きく、かつ発熱が大きくなるので冷却面での効率的な冷却が可能となる。

【００３７】図４は、固体レーザ結晶の第１の実施例の結晶内の温度分布を計算した結果である。励起光の吸収量は冷却面の近くで大きくなるため、温度上昇のピークが冷却面側に移動するとともに、上昇値が２６度以下に抑えられることが判る。なお、本計算においても、固体レーザ結晶１１の励起面１７及び側面２５からの冷却効果を考慮していないために、実際には、更に温度上昇が抑制されることになる。

【００３８】次に本発明の固体レーザ結晶の第２の実施例について説明する。固体レーザ結晶の第１の実施例で示したＮｄ：ＹＡＧの場合、１ａｔｍ％台後半の濃度以上に増加させると、上準位寿命の低下を生じるため、これ以上活性イオンの濃度を高くすることには限界がある。したがって層厚として４ｍｍほどの厚さが必要となる。これに対し、固体レーザ結晶の第２の実施例であるイットリビウム：ＹＡＧ（Ｙｂ：ＹＡＧ）では、２０ａｔｍ％まで上準位寿命の低下を生じさせることなく、活性イオンのドーブが可能である。

【００３９】図５は、Ｎｄ：ＹＡＧ結晶にかえてＹｂ：ＹＡＧ結晶を用いた場合の結晶中のレーザ活性イオンの濃度２１分布を表したものである。Ｙｂ：ＹＡＧでは、Ｎｄ：ＹＡＧに比べて高濃度ドーブが可能となるため、厚さ１．５ｍｍの結晶中を２往復することにより励起光の９９％のエネルギーが吸収されることになる。

【００４０】図６は、前述の固体レーザ結晶を用いた場合の上昇温度分布を表したものである。Ｙｂ：ＹＡＧでは層厚を薄くすることができるので、冷却面からのいっそうの冷却効果が得られ、上昇温度のピークは約２４．７度に抑制されることになる。

【００４１】なお、本発明の固体レーザ装置は、励起光１９である半導体レーザ１６をＶ字型に配置し、固体レーザ光２０を固体レーザ結晶１１に対して垂直に取り出す配置について述べたが、従来例と同様の構成をとって

も温度上昇の抑制効果を得ることは可能である。

【００４２】次に、本発明の固体レーザ結晶の作成方法と固体レーザ結晶の製造装置について図面を用いて詳細に述べる。

【００４３】図７は本発明の固体レーザ結晶の製造装置である第１の実施例の構成図であり、従来の固体レーザ結晶の製造装置と異なるのは、Ｎｄ：ＹＡＧ溶液３１を強制的に撹拌するための撹拌用ハネ３３を有する点である。撹拌用ハネ３３は、回転するアルミナ棒３２に保持されており、アルミナ棒３２とともに回転することにより、Ｎｄ：ＹＡＧ溶液を強制的に撹拌する。従来の作成方法では、出来る限り結晶の軸方向に濃度が均一になるように、回転速度及び引き上げ速度をそれぞれ、毎分２０回、毎時１ｍｍ程度にゆっくり引き上げ、軸方向に沿って均一な濃度を持つ固体レーザ結晶を育成していた。本実施例においては、回転速度及び引き上げ速度を従来の固体レーザ結晶の作成方法と同様にし、撹拌手段によりＮｄ：ＹＡＧの溶液を強制的に撹拌することで、ＮｄのＹＡＧに対する実効偏析係数を固有の偏析係数に近づけ、従来の育成方法に比べて急峻な濃度勾配を持つレーザ結晶の育成が可能となる。

【００４４】本実施例においては、強制的な撹拌手段である撹拌用ハネをアルミナ棒３２とともに回転させる方法について説明したが、別に駆動手段を設けて、強制的な撹拌を行うことも可能である。また本実施例では回転速度及び引き上げ速度を従来の固体レーザ結晶の作成方法より速くすることにより、例えば毎時１．５～２．５ｍｍ程度とすることで撹拌手段を用いずに急峻な濃度勾配を持つレーザ結晶の育成も可能である。

【００４５】図８は、本発明による固体レーザ結晶の製造装置を用いて作成したときの、固体レーザ結晶中の活性イオン濃度３４の分布を表したものである。結晶の長さは、相対値で表しており、相対長さ１が種結晶側３８に相当する。濃度は、Ｎｄ：ＹＡＧ溶液３１中のレーザ活性イオン濃度に対する相対値で表している。図８より明らかなように、濃度勾配は種結晶側３８へ行くにつれて急峻になる。結晶の濃度を相対濃度で表していることからも明らかなように、Ｎｄ：ＹＡＧ溶液３１中のレーザ活性イオン濃度を変えることにより、自由な濃度勾配を持つ固体レーザ結晶の作成が可能となる。また作成したＮｄ：ＹＡＧ結晶２７の中から、勾配ａ３５、勾配ｂ３６、勾配ｃ３７それぞれの部分を切り出すことにより、自由な濃度勾配を持つ固体レーザ結晶の作成が可能となる。

【００４６】次に、本発明の固体レーザ結晶の作成方法及び製造装置の第２の実施例について述べる。

【００４７】図９は固体レーザ結晶の製造装置の第２の実施例の構成図であり、レーザ活性イオン濃度の異なる４種類の溶液ａ４０、溶液ｂ４１、溶液ｃ４２、溶液ｄ４３を含むＩｒ製るつぼ２９及び固体レーザ結晶を溶液ａ４０～溶液ｄ４３へ順に移動するための結晶移動機構３９を有する。レーザ活性イオン濃度は、溶液ａ４０で最も高く、溶液ｄ４３へ行くにつれて低くなるように設定されている。

【００４８】本実施例の固体レーザ結晶の作成方法では、まず、溶液ａ４０において結晶を成長させる。所望の長さに達した時点で、結晶移動機構３９によりＮｄ：ＹＡＧ結晶２７を溶液ｂ４１に移動させ再び結晶を成長させる。これを、溶液ｄ４３まで繰り返す。これにより、結晶の長さ方向で勾配を持つ結晶の作成が可能となる。

【００４９】図１０は、本実施例の固体レーザ結晶の作成方法による固体レーザ結晶中のレーザ活性イオン濃度４８の分布を表したものである。勾配ａ４４、勾配ｂ４５、勾配ｃ４６、勾配ｄ４７は、それぞれ、溶液ａ４０、溶液ｂ４１、溶液ｃ４２、溶液ｄ４３において作成した濃度勾配である。完全に直線的な、勾配を作るのは困難であるが、図１０のような勾配を持つ固体レーザ結晶でも十分な温度上昇の抑制効果を得ることができる。また濃度の異なる溶液の種類を増やすことにより、より均一な濃度勾配を持つ結晶の作成が可能となりる。

【００５０】本実施例においては、固体レーザ結晶を移動させる方法について説明したが、溶液を移動させても、結晶の作成は可能である。

【００５１】次に、本発明の固体レーザ結晶の作成方法及び製造装置の第３の実施例について述べる。

【００５２】図１１は固体レーザ結晶の製造装置の構成図であり、Ｎｄ：ＹＡＧ溶液３１中に、レーザ活性物質の原料なる$Nd_2O_3$の粉末を注入するためのレーザ活性物質注入口４９が設けられている。

【００５３】本実施例による固体レーザ結晶の作成方法においては、まず、Ｉｒ製るつぼ２９中に、レーザ活性物質の原料粉末である$Nd_2O_3$を除く、$Al_2O_3$、$Y_2O_3$の粉末のみを導入し、レーザ活性物質の含まれないＹＡＧ結晶を成長させる。その後、時間とともにレーザ活性物質導入口４９より$Nd_2O_3$粉末を注入する。この方法により、時間とともにＮｄ：ＹＡＧ溶液３１中のレーザ活性イオン濃度を増加させることができ、レーザ活性物質の注入量と注入時間を変えることにより、種結晶側で濃度の低く、離れるほど高くなる濃度勾配を持つ結晶を成長させることが可能となる。

【００５４】次に、本発明の固体レーザ結晶の作成方法及び製造装置の第４の実施例について述べる。

【００５５】図１２におけるレーザ結晶の製造装置では、均一な濃度を持つ固体レーザ結晶５０を結晶の軸方向に沿って移動可能なヒータ５０の間に保持されており、ヒータ５０は、結晶の一部を熱し溶融帯を作りながら、左から右へ移動する。このような作業を繰り返すことにより、レーザ活性イオンであるＮｄ３＋は徐々に右側に移動することになる。

【００５６】図１３は、前述のレーザ結晶の作成方法を用いたときの、固体レーザ結晶中のレーザ活性イオン濃度の分布を表したものである。濃度は、初期のＮｄ：ＹＡＧ結晶５１のレーザ活性イオンの濃度に対する相対値で表しており、初期の濃度は、曲線ａ５２に相当する。ヒータ５０の移動を繰り替えすことにより、レーザ活性イオンの濃度分布は、曲線ｂ５３から曲線ｄ５５へ変化する。本作成方法では、初期に用いる結晶の濃度の違い、ヒータ５０の移動回数により、更に急峻な濃度勾配を持つ結晶の作成方法が可能となる。

【００５７】次に、本発明の固体レーザ結晶の作成方法及び製造装置の第５の実施例について述べる。

【００５８】図１４を参照すると、本発明の固体レーザ結晶の製造装置は、アルミナ棒５６に保持された、ＹＡＧ種結晶２６及び、Ｎｄ：ＹＡＧの原料となる$Al_2O_3$、$Y_2O_3$、及び$Nd_2O_3$の高純度の粉末を焼結させたＮｄ：ＹＡＧ焼結体５８、Ｎｄ：ＹＡＧ焼結体５８の一部を加熱溶融させるための赤外線６０を発生させるための赤外線発生装置５９を有する。Ｎｄ：ＹＡＧ焼結体５８は、あらかじめ、レーザ活性イオンの原料となるＮｄ２Ｏ３の濃度を軸方向に勾配を持つように作成してある。赤外線発生装置５９は、Ｎｄ：ＹＡＧ焼結体５９の周りを回転するとともに上下に移動するための移動機構６１を有する。

【００５９】本作成方法においては、赤外線発生装置５９は、Ｎｄ：ＹＡＧ焼結体５８の一部を加熱、溶融させながら、図面上のＹＡＧ種結晶２６より下方向へ回転、移動する。これにより、ＹＡＧ種結晶２６側から、徐々にＮｄ：ＹＡＧ焼結体５８の結晶かが始まり、Ｎｄ：ＹＡＧ焼結体５８中のレーザ活性イオンの濃度勾配に応じたレーザ活性イオンの濃度勾配を持つ固体レーザ結晶が作成される。本作成方法においては、Ｎｄ：ＹＡＧ焼結体５８中に含まれるレーザ活性イオンの濃度を変えることにより、自由な濃度勾配を持つ固体レーザ結晶の作成が可能となる。

【００６０】次に本発明の固体レーザ結晶の第２の実施例について図面を参照して、詳細に説明する。

【００６１】本実施例では、直径６ｍｍ、厚さ４ｍｍのＮｄ：ＹＡＧ固体レーザ結晶に対して、図１５のように、励起面から冷却面までの厚さ方向の距離の２乗に比例してレーザ活性イオンの濃度６２を増加させている。励起面１７、冷却面１８での活性イオン濃度は、それぞれ、０．２、１．４ａｔｍ％である。このような濃度分布を持つことにより、固体レーザ結晶中に吸収される励起光吸収量６３は、図１６に示すように直線的な濃度勾配を持つ結晶に比べて、更に冷却面側で大きくなることが判る。

【００６２】図１７は、１０Ｗの半導体レーザにより固体レーザ結晶を励起したときの上昇温度の計算結果を表したものである。固体レーザ結晶の図２の例に比べて、上昇温度のピークは、冷却面側に移動するとともに、ピーク値は２３．４度と図２の直線的な濃度勾配を持つ場合に比べて、更に抑制することが可能となる。

【００６３】次に、本発明のレーザ結晶の第３の実施例について図面を参照して詳細に説明する。

【００６４】図１８（ａ）は、本発明の固体レーザ結晶の側面図、図１８（ｂ）はレーザ活性イオンの濃度分布を表す。図１８を参照すると、本発明の固体レーザ結晶は、レーザ活性イオン濃度の異なる４枚の結晶が接合されている。最も濃度の低い結晶ａ６５から濃度の低い順に接合されており、結晶ａ６５は、励起面１７に結晶ｄ６８は冷却面１８に配置されている。

【００６５】図１９は、励起光の吸収量６９を表したものであり、結晶ａ６５から結晶ｄ６８へ行くにつれて吸収量が大きくなるようになっている。更に、結晶の分割数を増やせば、図２の実施例に近づくことになる。

【００６６】図２０は、１０Ｗの半導体レーザにより固体レーザ結晶を励起したときの上昇温度の計算結果を表したものである。上昇温度のピーク値は２８．３度であり、図２の実施例と同様温度上昇の抑制効果が得られる。

【００６７】次に、固体レーザ結晶の第３の実施例を作成する方法について述べる。

【００６８】直径６ｍｍ、厚さ１ｍｍ、レーザ活性イオン濃度がそれぞれ、０．３５、０．７、１．０５、１．４ａｔｍ％であり、結晶軸の一致した４枚の結晶の両端を、λ／１０、平行度１秒に研磨したものを、オプティカルコンタクトにより接合する。これにより、接合面における光学的なロスのほとんど生じない固体レーザ結晶を作成することが可能となる。

【００６９】本実施例では、オプティカルコンタクトによる結晶の作成方法のみを述べたが、拡散接合による作成も可能である。

【００７０】次に、本発明の固体レーザ結晶の第４の実施例について図面を参照して詳細に説明する。

【００７１】図２１（ａ）は、本発明の固体レーザ結晶の側面図、図２１（ｂ）はレーザ活性イオンの濃度分布を表す。図２１を参照すると、本発明の固体レーザ結晶は、レーザ活性イオンのドープされていない結晶ａ７０と濃度勾配が直線的な勾配を持つ結晶ｂの２枚の結晶が接合されている。結晶ｂの接合面は、濃度の低い面であり、もう一方の面は冷却面に配置されている。

【００７２】図２２は、励起光の吸収量の割合７３を表したものであり、結晶ａ７０では、励起光の吸収は起こらず、結晶ｂ７４にて励起光が吸収される。

【００７３】図２３は、１０Ｗの半導体レーザにより固体レーザ結晶を励起したときの上昇温度の計算結果を表したものである。上昇温度のピーク値は２５．８であり、図２に示す実施例に比べて０．２の温度抑制効果が得られている。実際には、側面からの冷却効果が得られ

るため、側面の表面積が図２の実施例に比べて２倍である本実施例では、より温度の抑制効果が得られる。更に、結晶ａ７０では励起光の吸収が起こらないので結晶の厚みを増やしても、温度上昇の抑制効果が低減しないため、機械的なひずみに対する強度の上昇効果が得られる。また第４の実施例ではドープ濃度が直線となっているがこれに限られるものではなく、固体レーザ結晶の第１～第３の実施例で述べた固体レーザ結晶にも用いることができる。

【００７４】なお固体レーザ結晶の第２～第４の実施例にレーザ活性イオンとしては、Ｎｄあるいはｙｂ等を用いることができる。

【００７５】

【発明の効果】本発明では、活性イオン濃度が励起面より冷却面で高い固体レーザ結晶を用いているために、効率的な冷却が可能になる。このため高出力化時の固体レーザ結晶内の温度上昇を抑制することができ、高出力化に伴う、ビーム品質の劣化を抑制することが可能となる。

【図面の簡単な説明】

【図１】本発明に用いた固体レーザ装置の全体構成を示す図である。

【図２】本発明の固体レーザ結晶の第１の実施例であるＮｄ：ＹＡＧ結晶内のレーザ活性イオンの濃度分布を示す図である。

【図３】本発明の固体レーザ結晶の第１の実施例であるＮｄ：ＹＡＧ結晶内の励起光の吸収量の割合を示す図である。

【図４】本発明の固体レーザ結晶の第１の実施例であるＮｄ：ＹＡＧ結晶内の上昇温度分布を示す図である。

【図５】本発明の固体レーザ結晶の第１の実施例であるＹｂ：ＹＡＧ結晶内のレーザ活性イオンの濃度分布を示す図である。

【図６】本発明の固体レーザ結晶の第１の実施例であるＹｂ：ＹＡＧ結晶内の上昇温度分布を示す図である。

【図７】本発明の固体レーザ結晶の製造装置の第１の実施例を説明するための図である。

【図８】本発明の固体レーザ結晶の作成方法の第１の実施例により作成したＮｄ：ＹＡＧ結晶内のレーザ活性イオン濃度を示す図である。

【図９】本発明の固体レーザ結晶の製造装置の第２の実施例を説明するための図である。

【図１０】本発明の固体レーザ結晶の作成方法の第２の実施例により作成したＮｄ：ＹＡＧ結晶内のレーザ活性イオン濃度を示す図である。

【図１１】本発明の固体レーザ結晶の製造装置の第３の実施例を説明するための図である。

【図１２】本発明の固体レーザ結晶の製造装置の第４の実施例を説明するための図である。

【図１３】本発明の固体レーザ結晶の作成方法の第４の実施例により作成したＮｄ：ＹＡＧ結晶内のレーザ活性イオン濃度を示す図である。

【図１４】本発明の固体レーザ結晶の製造装置の第５の実施例を説明するための図である。

【図１５】本発明の固体レーザ結晶の第２の実施例であるＮｄ：ＹＡＧ結晶内のレーザ活性イオンの濃度分布を示す図である。

【図１６】本発明の固体レーザ結晶の第２の実施例であるＮｄ：ＹＡＧ結晶内の励起光の吸収量の割合を示す図である。

【図１７】本発明の固体レーザ結晶の第２の実施例であるＮｄ：ＹＡＧ結晶内の上昇温度分布を示す図である。

【図１８】本発明の固体レーザ結晶の第３の実施例を説明するための図及びレーザ活性イオンの濃度分布を示す図である。

【図１９】本発明の固体レーザ結晶の第３の実施例であるＮｄ：ＹＡＧ結晶内の励起光の吸収量の割合を示す図である。

【図２０】本発明の固体レーザ結晶の第３の実施例であるＮｄ：ＹＡＧ結晶内の上昇温度分布を示す図である。

【図２１】本発明の固体レーザ結晶の第４の実施例を説明するための図、及びレーザ活性イオンの濃度分布を示す図である。

【図２２】本発明の固体レーザ結晶の第４の実施例であるＮｄ：ＹＡＧ結晶内の励起光の吸収量の割合を示す図である。

【図２３】本発明の固体レーザ結晶の第４の実施例であるＮｄ：ＹＡＧ結晶内の上昇温度分布を示す図である。

【図２４】従来の固体レーザ装置の全体構成を示す図である。

【図２５】従来の固体レーザ結晶の製造装置を説明するための図である。

【図２６】従来の固体レーザ装置の固体レーザ結晶内の励起光吸収量の割合示す図である。

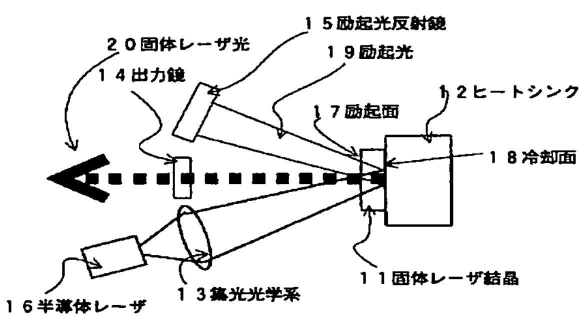
【図２７】従来の固体レーザ装置のレーザ結晶内の上昇温度分布を示す図である。

【符号の説明】

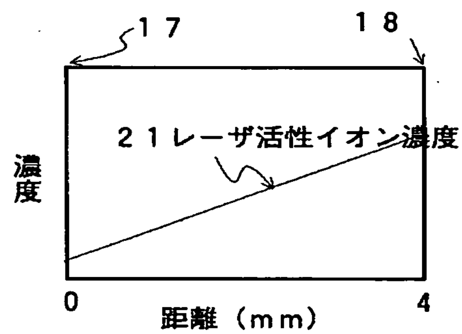
１０　反射鏡
１１　固体レーザ結晶
１２　ヒートシンク
１３　集光光学系
１４　出力鏡
１５　励起光反射鏡
１６　半導体レーザ
１７　励起面
１８　冷却面
１９　励起光
２０　固体レーザ光
２１　レーザ活性イオン濃度
２２　励起光吸収量

２３　結晶中心
２４　上昇温度
２５　結晶側面
２６　ＹＡＧ種結晶
２７　Ｎｄ:ＹＡＧ結晶
２８　アルミナ断熱材
２９　Ｉｒ製るつぼ
３０　誘導加熱用コイル
３１　Ｎｄ:ＹＡＧ溶液
３２　アルミナ棒
３３　撹拌用ハネ
３４　レーザ活性イオン濃度
３５　勾配ａ
３６　勾配ｂ
３７　勾配ｃ
３８　種結晶側
３９　結晶移動機構
４０　溶液ａ
４１　溶液ｂ
４２　溶液ｃ
４３　溶液ｄ
４４　勾配ａ
４５　勾配ｂ
４６　勾配ｃ
４７　勾配ｄ
＊４８　レーザ活性イオン濃度
４９　レーザ活性物質注入口
５０　ヒータ
５１　Ｎｄ：ＹＡＧ結晶
５２　曲線ａ
５３　曲線ｂ
５４　曲線ｃ
５５　曲線ｄ
５８　Ｎｄ:ＹＡＧ焼結体
５９　赤外線発生装置
６０　赤外線
６１　赤外線発生装置移動機構
６２　レーザ活性イオン濃度
６３　励起光吸収量
６４　レーザ活性イオン濃度
６５　結晶ａ
６６　結晶ｂ
６７　結晶ｃ
６８　結晶ｄ
６９　励起光吸収量
７０　結晶ａ
７１　結晶ｂ
７２　レーザ活性イオン濃度
７３　励起光吸収量＊

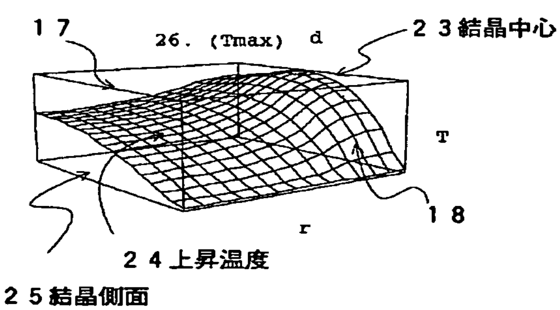
【図１】



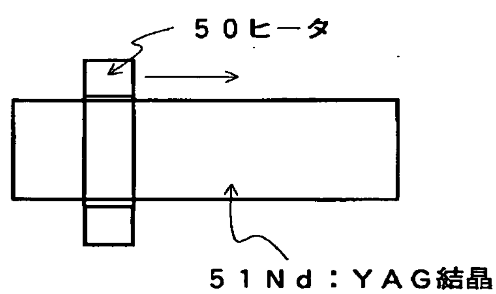

【図２】



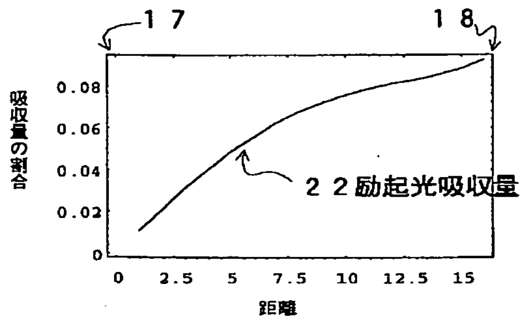

【図４】



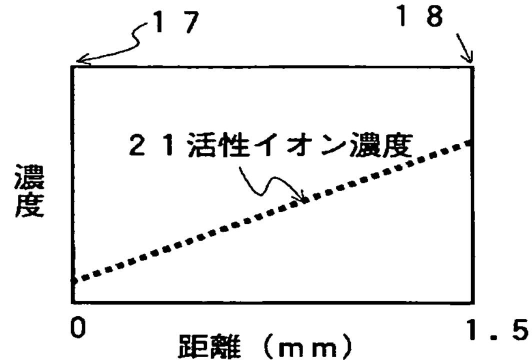

【図１２】



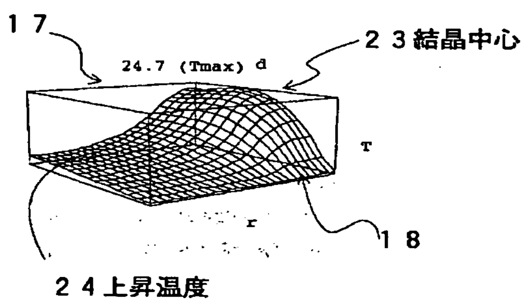
【図３】



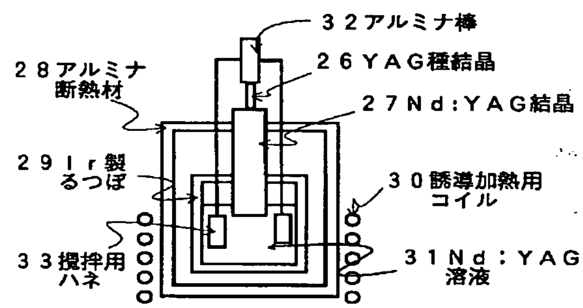

【図５】



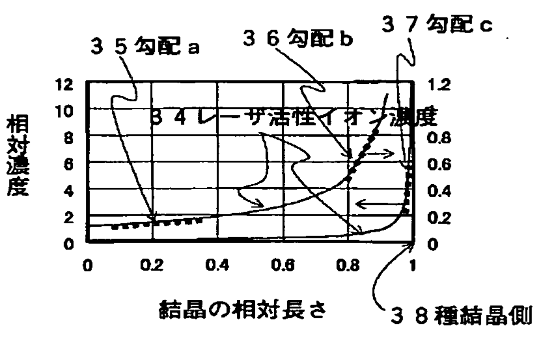

【図６】



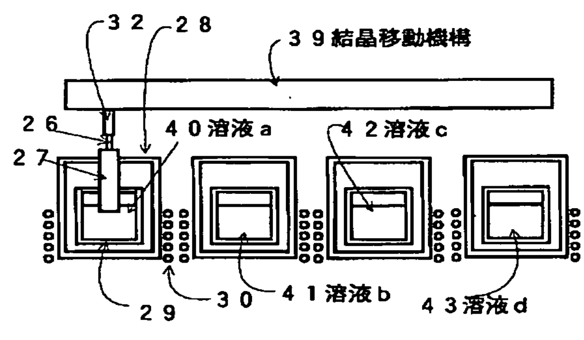

【図７】



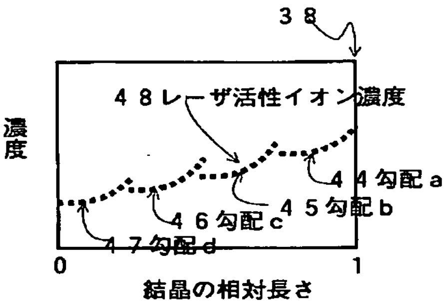

【図８】



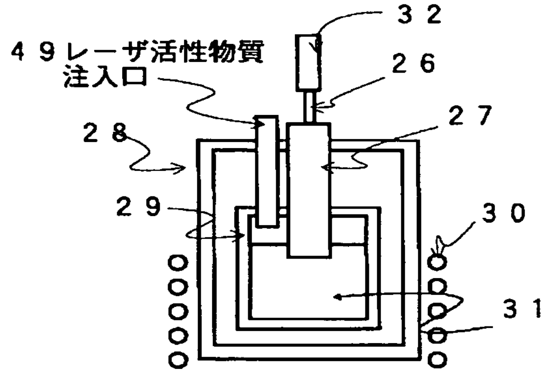

【図９】



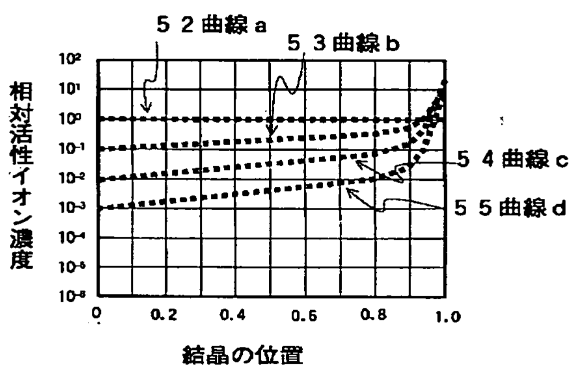
【図１０】



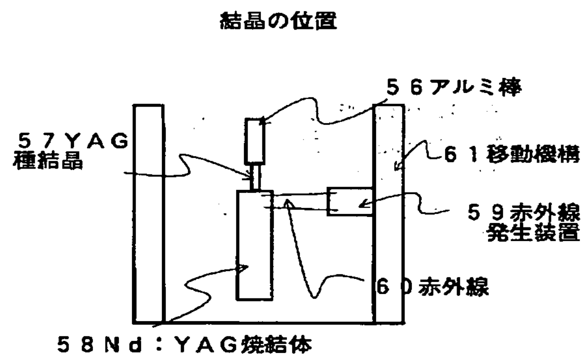

【図１１】



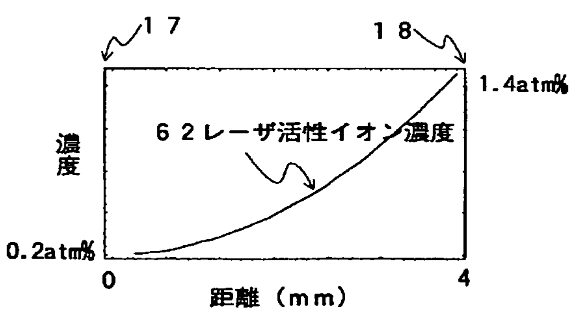

【図１３】



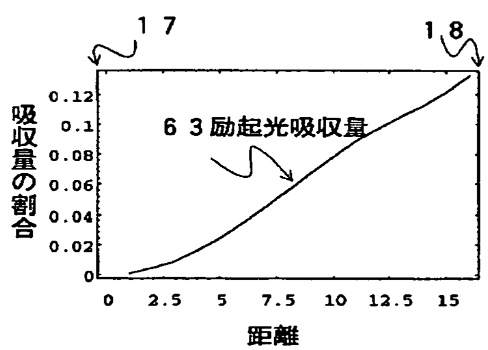

【図１４】



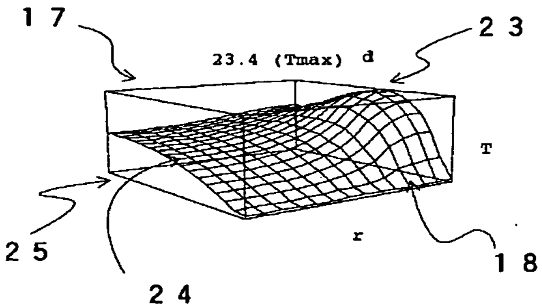

【図１５】



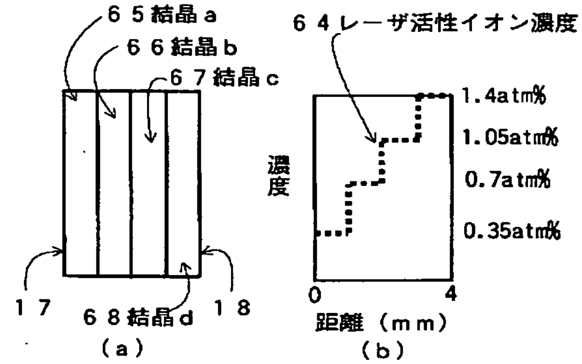

【図１６】



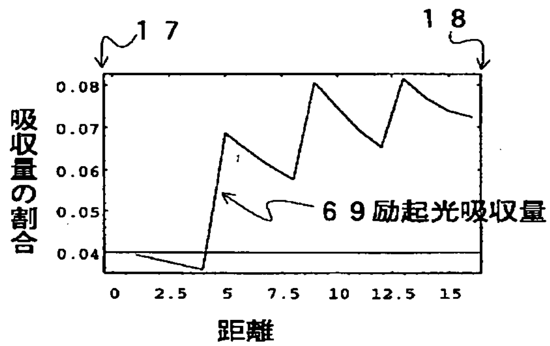
【図１７】



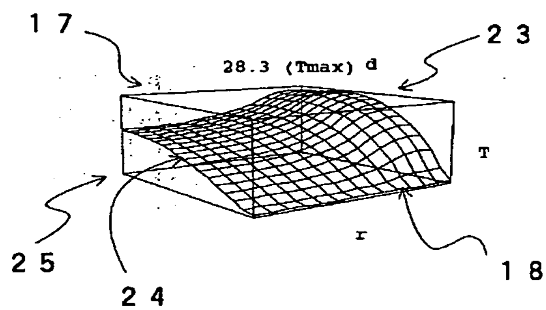

【図１８】



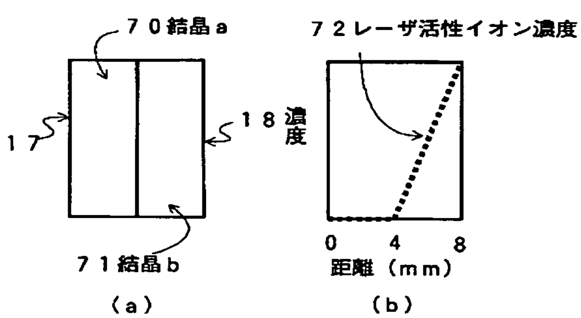

【図１９】



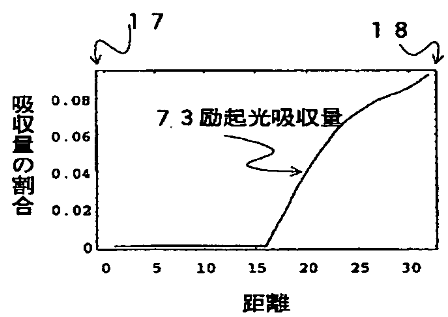

【図２０】



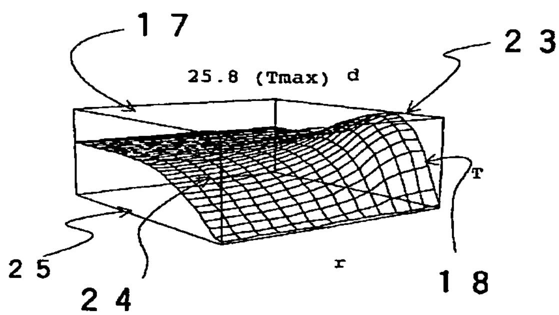

【図２１】



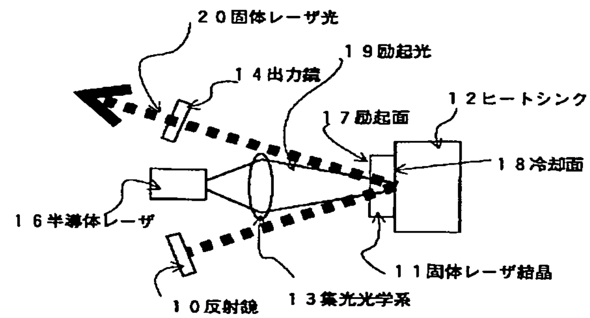

【図２２】



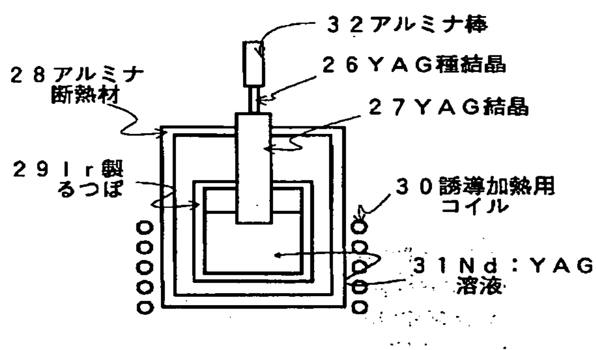
【図２３】



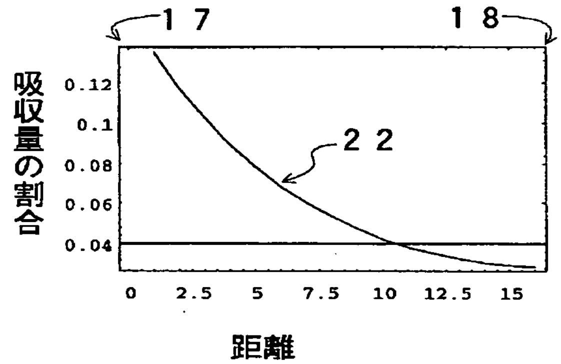

【図２４】



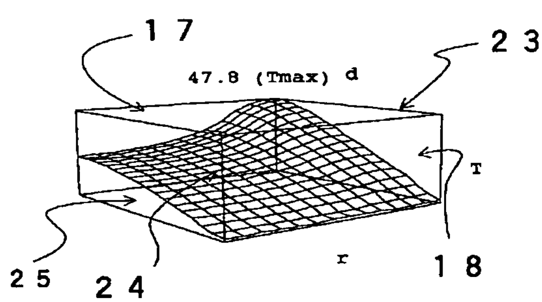

【図２５】




【図２６】




【図２７】




---

フロントページの続き

(58)調査した分野(Int.Cl.⁷，ＤＢ名)
H01S 3/00 - 3/30
C30B 15/04